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AN UNTRIED METHOD OF DETERMINING THE CONSTANT OF REFRACTION.

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FOR POPULAR ASTRONOMY.

The refraction tables used in reducing the observed zenith distance of a heavenly body, to obtain its true zenith distance, have been constructed, by adjustment, from meridian or vertical circle measurements of a star, both above and below the celestial pole.

In the reduction of an observation of that character, the plan has been to assume a certain latitude for the instrument, a certain law of refraction, and then by a least square adjustment bring forth corrections to the assumed latitude, and the assumed law of refraction that will reduce the difference between the declinations secured of each star, both above and below the pole, to a minimum.

The refraction tables, prepared by Bessel, were for years the standard used in all Observatories engaged in obtaining declinations of heavenly bodies. The more recent ones, based upon the very accurate series of star places secured by Dr. Nyren, and other astronomers at the Pulkova Observatory, are now considered to be nearer the true refraction for all zenith distances.

Each of these tables are the result of data obtained from measurements of zenith distance on the arc of a divided circle, either in the form of a Meridian or a Vertical Circle. The method has involved in it the error of the graduations on the circle, unless every one has been accurately obtained, the error of flexure of the instrument, and it starts out with an assumed law of refraction, which in itself may be imperfect.

It must be admitted that our present knowledge of that law needs a more exhaustive investigation by other observational plans, for as progress is made toward refined processes of measurements of stellar positions conditions present themselves that indicate a lack of knowledge of the true basis of that constant.

In the past decade, one of the most energetic crusades has

been carried on by astronomers, toward solving the problem of what is the true Constant of Aberration. For years the classical value secured by Struve had not been questioned, but now it is known that the Aberration Constant is from 0.08″ to 0.10″ greater than the one so long in general use.

It does not seem unreasonable to suggest, that a factor involved in so marked a manner in all star places, should be based upon more than one method of obtaining it. Moreover, the several fundamental constants in astronomy, namely, aberration, nutation, solar parallax, and others, have been derived by different processes, either observational or indirectly from that, but that of refraction has only been secured from data collected in accordance with the scheme just outlined.

Again, both of the tables mentioned are the result of a relative procedure, which by an independent and absolute determination, might bring to light the cause for the large differences that appear in individual observations made at low altitudes.

The Bessel and the Pulkova tables are the result of measured declinations in relatively high latitudes. I do not know of a single instance in which the base of refraction has been secured from star places in latitudes less than forty-five degrees, in a climate in which relatively high temperatures prevail at certain seasons of the year, or in which zenith distances at those high temperatures were measured on a perfectly dark sky.

Mr. R. M. Crawford, formerly of the Lick Observatory, has recently published some very interesting investigations of the refraction constant, based upon what may be termed a modified form of Talcott's method, namely, observing pairs of stars with a meridian circle, at approximately equal distances north and south of the zenith.

The scheme of observing used by Mr. Crawford is a differential one, because the refraction constant secured depends upon whose fundamental stars one selects for the plan of work. If the Boss, Newcomb, or Auwers fundamental places of the same stars are each in turn compared with the declinations Mr. Crawford has obtained from his observations, one will derive a different value for the Constant for each of the three sets. The difference Newcomb minus Boss, or Newcomb minus Auwers for each star is not zero, and if it were so there still remains the proof that each of the star places in the catalogues is the actual position of the object in the heavens.

From another condition, that south of forty-five degrees north latitude, or the reverse of that south of the equator, an observer

is confronted with a large gap of zenith distance over which it is impossible to observe stars above and below the pole, and thus secure the same reference points for the two sets of observations, acts as a bar to the wishes of many observers who desire to obtain the value of the refraction constant in the climatic conditions, and topography of country that surrounds their instrument.

Here in Washington our latitude is north 38° 55′, and we are unable to observe a star at its lower culmination, whose declination is less than fifty-six degrees. The more I study the results of the computer, bringing into a final place, the star positions secured in so many latitudes, the more convinced I become that at those Observatories constantly engaged in measuring zenith distances, the refraction used in the reduction should be based on the Constant that has been determined at each of the Observatories.

Moreover, it has been shown that what has been supposed to be a constant is not so, but that the base of refraction, as a unit, has different values, as a unit, at different zenith distances. The results at Lick Observatory, located on a high mountain, and those secured at Pulkova, situated near the sea level, have amply confirmed the above.

The local conditions existing near each transit circle, the material with which the house is constructed, and the topography of country in the immediate vicinity, differ materially at all observatories, and the refined results flowing from our standard instruments should be reduced with that refraction factor that best meets the requirements of those local conditions.

An appropriate example of this will be found in the surroundings at the old Naval Observatory, and the effect upon the measured zenith distances. The building in which the instrument was housed was located on the north east bank of the Potomac River, and all stars south of the celestial equator were observed through a column of air rising from the river. To the north that condition did not prevail.

Professor J. R. Eastman has shown in the introduction to the second Washington Catalogue, page LVII, that should the temperature of the air, as recorded from readings of the thermometer near the large transit circle, be changed by 0.7 deg. Fah., it would smooth out the residuals that were found to be a function of the zenith distance of the southern stars. This refraction correction was not confined to the results secured from the large transit circle, but the same peculiarity was found to

exist in the residuals secured from observations made with the mural circle.

Now to turn to the suggestions I will make, suppose one establishes in the plane of the prime vertical, an instrument similar in form and of the rigidity of parts, of the modern zenith telescope. I will assume that a divided circle, capable of being read to single seconds of arc, is a part of the instrument, that two levels of precision are attached to the telescope tube, after the manner adopted in the zenith telescope, and the telescope tube, levels, and circle, mounted on a vertical axis of the highest workmanship, free from torsion or spring.

It is extremely essential that the vertical spindle on which the instrument is turned in azimuth should be extremely rigid, with respect to the telescope, because in reversing, it is paramount that the least possible change of verticality of the apparatus occur during an interval that may be from ten to fifteen minutes.

At the eye end there should be placed a reticule of horizontal threads, for the stars to be observed will appear to move in a vertical direction. A very convenient auxiliary could be fastened to the eye piece, namely, a reversing prism, so that the apparent motion of the star to be observed could be made to move in opposite directions.

In addition, two stops should be fastened to the base of the instrument, so that when it is turned either to the east or to the west, its line of collimation will be the prime vertical.

We now select two stars having a difference of about twelve hours in right ascension, but both of nearly the same declination. Successive transits of a pair of stars of that character across the horizontal threads will give data from which to obtain the amount of refraction at their zenith distance. Additional pairs of stars will give it at that corresponding to their zenith distance.

As an illustration of the method, suppose the east star of a pair crosses before the west star. The instrument is set at the proper zenith distance, which is a matter of easy computation, the level bubble is brought to the center of its box, so as to represent the plane of the horizon, the same as would be done in making a zenith telescope observation, and the vertical transits of the star recorded on the chronograph. Readings of the level are made, the instrument revolved 180° in azimuth, and when the west star is seen, vertical transits of it are recorded in the same manner as for the first star. The level readings are again taken, and the observation is finished. The rate of the clock, which of course must be kept small, would have no appreciable effect

upon the two hour angles in the interval between the two transits.

Now turning to the observational data secured, it will be noted that the arithmetical sum of the hour angles of the two stars, which of course in each case is the difference in time between the right ascension of the star, and the instant it crossed the prime vertical, will differ from the difference between their right ascensions, by twice the refraction, expressed in time, at the zenith distance at which they were observed. It hardly seems necessary to state that the effect of refraction will be to elevate the position of each star, making their hour angles from the meridian shorter, and in consequence the observed will always be less than the true hour angle for each star.

The error of collimation of the instrument, which is involved in both transits, will be eliminated from the sum of the hour angles, because of the reversal of the telescope. The level bubble will indicate any change of verticality of the apparatus, between the time of making the two transits, and that can be taken account of in the reduction. If the instrument should not be exactly 90° from the meridian, a differential formula can be constructed that will correct the time for azimuth error.

The right ascension of each pair of stars must be rigidly known, for on that, in a great measure depends the accuracy of the results. However, if the observations were made on the equator that would not be so necessary. We do not need to know the correction to the clock used, with any thing more than fair accuracy, for it is not to be used in the reduction of the observations.

Assuming for the moment we know the true right ascension and declination of each of the stars, as well as the latitude of the instrument, we can compute from the triangle formed by the apparent hour angle, the latitude and the declination, the star's apparent zenith distance. Hence we have in our observation just what we want, the true refraction for an apparent zenith distance. In other words, we are able to compute from what we have secured, and with the highest degree of accuracy, the zenith distance of the star when it passed the middle thread of the transit instrument, and the absolute refraction at that zenith distance existing under the condition of temperature and pressure of the air then obtained from readings of the thermometer and barometer.

The ideal place for obtaining the Constant of Refraction in accordance with this scheme would be at the Earth's equator, because the same pair of stars would reverse themselves in crossing the east and west part of the prime vertical circle, respect-

ively, in an interval of six months.

However, the method may be used in latitudes somewhat distant from the equator, and give results of a high degree of accuracy. The most important point in this plan of operation is that it is free from all systematic errors in the instrument, it gives absolute refraction without any regard to an assumption of the law, and it removes all necessity of measuring on the arc of a divided circle.

To formulate the program of work, these conditions seem to be necessary. The pairs of stars should be selected of approximately the same magnitude, say of about 6.5 or 7.0 to free the work from a personal equation depending upon magnitude. The reversing prism should be so adjusted as to make the images of each pair appear to move through the field in the same direction or it could be so manipulated as to have one half of the transit threads crossed in one direction, and then reversed to secure the remaining ones oppositely. The Repsold self-registering micrometer would be of service in this investigation, if made in a simple form, and not liable to disturb the instrument in its manipulation.

The pairs of stars should be so spaced in right ascension as to permit the observer to have at his disposal an interval of from three to five minutes between transits in which to reverse the instrument.

The right ascension, as well as the declination, of each of the stars used in the investigation should be based upon a rigid determination of those two coördinates. The best possible value of the latitude of the instrument should also be secured.

So far I have only mentioned the observations as made up of a pair of stars. The pairs can be arranged in groups so as to eliminate other errors. To do this we must select groups of stars that will complete a cycle in a year. I would suggest the following arrangement:

Form four groups, whose mean right ascension is six, fourteen, eighteen, and twenty-two hours. The plan of operation would be to observe two of these groups each night, each containing as many pairs as could be put in two hours of observing. As soon as one set had come out in the day light another group could be taken up, and thus continued throughout the year. The groups should be selected to cover a certain portion of the zenith distance through which the refraction investigation is to be made. Another distinct set could be selected to cover another portion of zenith distance, and in this manner the whole arc from the zenith

to the horizon covered by a set of observations. All of them, however, should be continued for a year.

In the reduction of the observations, the systematic errors in right ascension, so far as they depend upon the right ascension, would vanish, because the sum throughout the year would be zero.

So far as I am aware this scheme of obtaining the Constant of Refraction has never been given a practical test. I am confident with the aid of a first class instrument, in the hands of a skillful observer, who would devise means of improvement beyond what I have suggested, the plan would yield valuable results, and enhance our present knowledge of the refraction law, especially at large zenith distances.

To make the investigation complete, one set of observations should be made in the observing house in which the instrument is located, and the other with the apparatus completely in the open air.

In conclusion I might add, this form of investigation would permit the observer to secure valuable data upon which to base a correction to the Constant of Aberration used by him in the reduction of the star places from mean to apparent.

Washington D. C.

FLAMSTEED AND PIAZZI IDENTITIES:—

Notes on the Nomenclature of Some Piazzi Stars.

HERMAN S. DAVIS.

For Popular Astronomy.

It seems to me that, some time ago, I saw a statement that Admiral Smyth learned from Piazzi, while helping him revise proof-sheets of the catalogue of 1814, that very special attention had been paid to getting the correct names of the stars as they are now found in that edition. I have been unable to find this quotation when looking for it again to insert here, and it may be that I have confused it with some similar remark regarding the magnitudes of the stars, or some other feature of the catalogue. But whether this statement has been printed or not, I have found it to be true, in so far, at least, as the Flamsteed numbers are concerned. At the present writing the investigation in nomenclature has extended no farther than that.

Last winter, as a thesis for the Master's degree at Wellesley

College, Miss Elizabeth M. Kittredge, First Computer on the NEW REDUCTION OF PIAZZI'S OBSERVATIONS, reduced all Flamsteed's positions to 1800 and identified as many of them as possible with Piazzi's stars, as definitive nomenclature for the new Piazzi catalogue. As a large majority of these identifications agreed with those given in the edition of 1814 it was proof of the care exercised by Piazzi,—probably as great care as was possible with only such guides as existed in the very few catalogues available at that early day.

There were a number of interesting cases of identity noted by me, however, which justify some remarks.

In the first place, Piazzi seems to have followed very closely the names given by Wollaston in his "Specimen of a General Astronomical Catalogue" printed in London in 1789. In fact he states very frankly in the preface to the first edition of his catalogue that Wollaston was used as his guide, throughout, in compiling the list of stars to be observed each night. Judging from his correspondence with Oriani, there seems to have been but very scanty additional sources of information at his disposal, even of the books in general circulation in northern Europe. For this reason, it is not infrequently that we find an error in Wollaston reproduced by Piazzi. Also in a number of cases where Piazzi concluded that a star was missing from the sky, the mistake arose usually from one or more of three causes: an error in Flamsteed's catalogue, reproduced by Wollaston; an error by Wollaston in reducing Flamsteed's position to 1790; or an error by Piazzi in reducing the position given by Wollaston to the date of his observing-list.

Let us take up the special cases which require some comment in explanation of my identification of the Flamsteed and the Piazzi positions, or of the causes which misled Piazzi into the identity published in the catalogue of 1814.

24 Sagittarii. Piazzi assigns this name to his XVIII:99 with which it agrees in right ascension, but Flamsteed's position is five minutes farther north. Auwers assigns the Flamsteed number to XVIII:105, with which it agrees in declination, but has a right ascension forty seconds smaller than Piazzi's. It is more probable that the latter identification is correct in view of the magnitudes of the respective stars. But it is possible that Flamsteed observed both stars, and in some way gave the right ascension of the earlier star and the declination of the later star as applying to the same object in the sky. This kind of mistake is one which has happened not infrequently, even with modern observers, especially when the two coördinates are determined on two different instruments. See preface to the Yarnall cat-

alogue and other publications of the Naval Observatory: also the Armagh catalogue and Memoirs of the Royal Astronomical Society, IV:138–9.

41 Cancri. According to the position given by Flamsteed this is properly identified with Piazzi's VIII:130, although it differs by two minutes in declination and a few seconds in right ascension from Piazzi's position. According to Wollaston, La Caille gives the name "Praesepe" to 39 Cancri, which is Piazzi VIII:126, whereas the name "Praesepe" is given by Piazzi to his VIII:130, which I have assumed agrees with Bayer's ε and Flamsteed's 41 Cancri. It is probable that Piazzi did this on the assumption that the star he observed is the brightest star nearest the center of this cluster. I call attention to it here as indicative only of the fact that Piazzi did not always follow Wollaston's nomenclature, although the exceptions are rare.

2 Vulpeculae. This star was observed by Flamsteed only approximately. Indeed, it may not have been observed at all, for his catalogue gives Hevelius as authority for its existence. In my opinion this star is identical with Lalande 36352-3, but as it was not included in Wollaston's catalogue, it was not inserted in Piazzi's observing list.

40 Aurigae. This is given by Wollaston correctly according to Flamsteed's observation reduced to 1790. It is the same as Groombridge 1075. It was not observed by Piazzi, nor is it to be found in his list of "Stellae non Repertae" in appendix to the edition of 1803. It seems to have been merely overlooked when making out lists for observing.

39 Cancri. Flamsteed agrees with La Caille in giving the name "Praesepe" to this star, which has been identified with Piazzi's VIII:126. According to Wollaston, it was Mechain who first pointed out that here Flamsteed had transposed the north polar distance of 39 Cancri and 40 Cancri. Piazzi did not follow this error, obviously because he had Wollaston's memorandum to this effect for his guidance.

40 Cancri. See the comments made above for 39 Cancri.

19 Cygni. This star is not found in Piazzi's catalogue. It is an interesting illustration of how he attempted to follow Wollaston, but mistook the identity of the star in the heavens. In the Storia Celeste, volume I, page 98, in connection with his observation of XIX:304, Piazzi states that this star is *followed* by another. Flamsteed, in volume II, page 123 of his Historia Coelestis (edition of 1725), says that the star he observed is *preceded* by another, which is to the south. It was this preceding star which Piazzi observed, and the second star (which undoubtedly was the one Piazzi purposed to observe) was omitted for catalogue purposes by reason of the difference of one minute in the right ascension, and the absence of a note in Wollaston to indicate which star was observed by Flamsteed.

4 Monocerotis. This is another star which is not in Piazzi's

catalogue. It will be seen by reference to Wollaston that Flamsteed's declination reduced to 1790 was made forty seconds too small by Wollaston. Hence, Piazzi in observing overlooked it because he supposed his V:339 was closely enough in agreement with Flamsteed's position, as given by Wollaston, to be the same star that was observed by Flamsteed. In accepting this conclusion, he never waited at the telescope to see the star which came a minute and a half later.

72 Aquarii. Wollaston correctly reduced Flamsteed's position to 1790, and also brackets with it Mayer 939, thus assuming that there was an error of three degrees in Mayer's declination. But Piazzi, finding that Mayer's position was correct, assigned his number as the name of this star, which is Piazzi XXII:230, and failed to note that it was the same star which Flamsteed had put in his catalogue as 72 Aquarii. Wherefore Piazzi inserts 72 Aquarii, with its erroneous declination, among his "Stellae non Repertae" in the appendix to his catalogue. (See in this connection, Wollaston's note in Zone 95°).

50 Arietis. This is Piazzi II:230, from which Flamsteed's position disagrees by being one minute too large in right ascension, and about half a minute too small in declination. Also the correct degrees of declination are 17°, but Wollaston, by erroneous reduction of Flamsteed's observation to the epoch 1790, makes this star at declination 16°. Consequently Piazzi did not recognize his II: 230 as being the same star, especially in view of the attendant disagreement in right ascension,—and thus replaced the name 50 Arietis by 75 LaCaille.

104 Aquarii. Although Flamsteed does not give any right ascension for this star, it seems to be correctly identified with Piazzi's XXIII:156, to which Piazzi has given the name 104 Aq. a^2 Hev. The source of such a designation as this is very interesting: but is easily explained by reference to Wollaston, who, in Zone 108°, has omitted the Flamsteed number purely by accident, and has inserted "Hevelii 45". He has correctly indexed this star, however, under its Flamsteed number. This has led Piazzi to insert the Flamsteed number and constellation, and the Bayer letter, but to attribute them all to Hevelius.

14 Ceti. At star 0:120 Piazzi calls this "Pisc. 14 Mayer". The identity of this star with 14 Ceti of Flamsteed was not known to Piazzi because of an error of three degrees in Flamsteed's observation. Wollaston gives this star in Zone 94° according to the position recorded by Flamsteed, but also in Zone 91° he gives the correct position as taken from No. 13 in Mayer's catalogue. As these two positions for the same star were 3° apart and fell in different zones in Wollaston, it was natural that neither he nor Piazzi should notice that the different observations belonged to the same star. Hence Piazzi places 14 Ceti in his list of "Stellae non Repertae."

55 Camelopardali. This is Groombridge 1404 but is not in

Piazzi's catalogue. The position observed by Hevelius, as given by Wollaston, is one minute less in right ascension than it should be according to Groombridge, and about forty seconds north of either Groombridge's or Flamsteed's position. It is probable that these errors in Wollaston, due to the incompleteness of Flamsteed's observation, prevented Piazzi from finding the star in the sky. It is all the more likely that this is the case since Piazzi made an additional error in the reduction to 1800 from the epoch of Wollaston's catalogue, for he has, thereby, diminished the right ascension by another minute, thus looking for the star two minutes too soon. Hence this star also went into his list of "Stellae non Repertae".

25 Canum Venaticorum. This star is probably LaLande 25193. It is not found in Piazzi's catalogue, because Wollaston, following Flamsteed, has put it in a zone ten degrees too far north.

9 Lyncis. Piazzi has assigned to his star VI:123 the name 7 Lyncis, although its position coincides with Flamsteed's position for 9 Lyncis. This is due to an error of one degree in declination, made by Flamsteed for 7 Lyncis, whereby it falls in Wollaston's zone 33° by the side of 9 Lyncis. This caused Piazzi to regard the name of his star as 7 Lyncis, attributing the two observations to the same star.

16 Lyrae. This is undoubtedly Piazzi XVIII:299, to which he has assigned the name 12 Hevelius. Flamsteed's observation is nine degrees too small in declination so that the identity naturally escaped Piazzi's attention, for he followed Wollaston as usually, and the latter gives the correct position in Zone 43° as taken from Hevelius. But Wollaston also gives Flamsteed's erroneous position in Zone 53°, adding to it an erroneous right ascension caused by a blunder of his own in reducing from 1690 to 1790 with an incorrect precession.

63 Orionis. Flamsteed's right ascension for this star is two minutes and twenty seconds too small. As this error was perpetuated by Wollaston, Piazzi did not notice its identity with his V:321, but placed the Flamsteed name among his list of Stellae non Repertae.

1 Sagittarii. This is Piazzi XVII:386. Wollaston gives as the precession constant in declination + 3″.57, but this is wrong since the right ascension in Flamsteed, by which it was computed, is forty minutes too small. This has made the declination printed by Wollaston for 1790 too large by 6′ 30″, in addition to a misprint of two degrees repeated from Flamsteed. With this combination of three large errors in Piazzi's guide, it is obvious why he could not find the star in the sky, and was compelled to insert it in the list of Stellae non Repertae. That Piazzi did, however, actually observe this Flamsteed star is because Wollaston gives it in Zone 113° in the correct position as deduced from No. 718 in Mayer's catalogue.

99 Tauri. Both the right ascension and the declination given by Flamsteed for this star are erroneous. Since Wollaston repeats these errors in his catalogue, Piazzi regarded 99 Tauri as not found, although his IV:243 is undoubtedly the Flamsteed star. He could pick it up in the sky because Wollaston inserts the correct position from 147 LaCaille and also 179 Mayer.

9 Tauri. This is Bradley 494, but it is not in Piazzi's catalogue, because Wollaston made an error of two degrees in declination in transcribing it from Flamsteed, placing it in Zone 69° instead of 67°. An approximate observation of the right ascension was made by Piazzi on one night, but the result was regarded as too inaccurate to be inserted in the catalogue.

25 Virginis. Although Flamsteed is in error in both the right ascension and the declination, Wollaston clearly shows that error by bracketing Flamsteed's position with the correct ones from LaCaille and Mayer. Hence Piazzi was prepared to recognize the identity of Flamsteed's star and his own and consequently assigned the correct Flamsteed name to his XII:136.

101 Virginis. This is Lalande 26156, but differs from Lalande's position by being one degree farther north. This error in Flamsteed prevented Piazzi from finding the star and placing it in his catalogue.

34 Vulpeculae. As Flamsteed's position for this star is ten minutes too early, and is reprinted by Wollaston with the same error, the reason for its omission from Piazzi's catalogue is obvious. It is Lalande 41512-3.

2 Ursae Minoris. This star observed by Flamsteed may be identical with Piazzi's 0:220 to which Piazzi has given the name Cephei 43 Hev. But it would be impossible by any rational *a priori* assumptions to revise the erroneous position given by Flamsteed. It is possible to identify Flamsteed's star with some star in the sky only by recourse to the original manuscripts. This has been done by Baily, but the corrigenda given in his note on this star are so extended and so complex, that even if we are justified in admitting the soundness of his conclusions, it is nevertheless undoubtedly better to place its identity with Piazzi's 0:220 in brackets, and assign to the Piazzi star the number and name accorded it by Hevelius. But even the long series of errors by Flamsteed seem not to have been sufficiently confusing, for Wollaston in reducing it to 1790 has introduced another error of four minutes in the right ascension. Piazzi inserted the name among his Stellae non Repertae.

29 Sextantis. This star can be identical with Piazzi X:86 only by assuming that Flamsteed's declination is one degree too far north. Wollaston has inserted in his Zone 90° the position given by Flamsteed as belonging to 29 Sextantis. In Zone 91° Wollaston gives as the declination of 28 Sextantis the same as was obtained by Piazzi but places it two minutes earlier in right ascension. As no star exists in the heavens at the position given

in Zone 90° naturally Piazzi with Wollaston as the usual guide, observed the star of Zone 91° and therefore used the name there recorded, namely 28 Sextantis. Equally naturally he recorded among his "Stellae non Repertae" 29 Sextantis as the missing star. In fact both records in Flamsteed should apply to the same star, and as Flamsteed's numbers depend on their sequence in right ascension and as his number 29 is the one having the correct right ascension it seems to me more logical to retain 29 as the star's name and discard the number 28 instead of vice versa.

57 χ^2 Orionis. Piazzi calls the star V:265 by the name 64 χ^4 Orionis but its position agrees with Flamsteed's 57 χ^2 Orionis. Piazzi's error in name is due to copying from Wollaston, who copied from Flamsteed, who made some errors in identifying his observation with Bayer's several χ-stars. This mistake on Flamsteed's part was because of errors in the sequence of his own stars in right ascension,—such, for example, as that of forty-five minutes in the right ascension of 65 Orionis thereby causing its insertion as a separate star when really it is identical with 62 Orionis, and a like error of forty-five minutes in 64 Orionis, causing it to follow 62 Orionis when really it should precede.

3 Arietis. This star and 57 Orionis described above are perhaps the most interesting cases of error piled on error causing additional errors or misunderstanding in many later catalogues. This 3 Arietis has often been cited as one of the three stars which furnished the most conclusive evidence of the actual disappearance of a star from the sky. In this connection it would be well for the reader to consult Baily's conjectures printed in the note on page 538 of the British Association Catalogue, and compare with page 77 of the same volume. Piazzi was not able to find the star in the heavens, although his memoranda seem to imply that he looked for it on several occasions at the place recorded by Wollaston. It is undoubtedly Bradley 234 with which it agrees within a few seconds of right ascension and a minute of declination, according to the position of Flamsteed. Now the primary basis of Baily's surmise as to the disappearance of this star was nothing more occult than an error of one degree ($= 4^m$) made by Wollaston in reducing Flamsteed's right ascension to 1790, and an additional error by Piazzi of four minutes in transcribing Wollaston's declination to his own observing lists.

Bearing these two errors in mind, it is easy to interpret every later error, remark, or surmise in all subsequent books. While the disappearance of this star has been refuted heretofore, I am not aware that this original source of all the misunderstandings about it has ever before been pointed out.

While the above notes do not embody all the discordances that will appear in the new edition of Piazzi's catalogue (now approaching completion), when compared with Piazzi's editions of 1803 and 1814, yet they are the only ones of special interest or importance, so far as the Flamsteed-numbers alone are concerned.

International Latitude Observatory,
Gaithersburg, Maryland,
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THE USE OF PHOTOGRAPHS IN TEACHING ASTRONOMY.

SARAH F. WHITING.

For Popular Astronomy.

In almost every exhibition there are pictures which fall under the condemnation of the critics as mere "studio productions." They may show fine technique, and much minuteness of detail, but one in sympathy with nature can tell at a glance that they were painted in the hard light of the studio, and not "in the open" with eyes constantly lifted to catch the varying lights and shades and colors of sky and landscape. So, many students get only class-room astronomy from text book and teacher, accompanied by little of that work with eye and hand now considered so essential in all study of science. With the best of intention to secure out of door observation, every teacher of astronomy knows how persistently fine evenings fall on Sundays and holidays, and how often the plan of work "by sections" is hopelessly thwarted by dense clouds or chill winds which make it unpleasant if not impossible, and when the rare fine evening comes there are so many to observe that it is impracticable to give each one time to make a drawing at the telescope.

Nothing can take the place of first hand observations of the gleaming silvery Moon, the flashing star, or the mottled surface of the Sun, but the necessarily limited number of these may be supplemented by the study of the photographs of celestial objects now taken in such perfection at the research observatories.

It is somewhat difficult to obtain the desired pictures in sufficient number for individual study, because the observatories busy taking them have no time to put them on the market, but if there were sufficient demand some supply could doubtless be secured in the way of the half tone pictures now so useful in many departments of school work. Of late the magazines have produced illustrations of astronomical articles which in absence of anything better might do good service.

The study of pictures is also of use in preparing the novice for intelligent observation, that his mind as well as his vision may be behind the eyepiece. The trained observer, it is well known, must take care to keep his judgment free from prejudice that he may not see a thing merely because it falls in with preconceived theory, but Faraday would say, when asked to observe a new experiment, "What am I to see"? that is, out of the multitude of

possible phenomena occuring, what is to be singled out for special attention.

Continuing the method adopted in previous articles, we will detail, by way of illustration, the plan found practical with us. In the course of the year we succeed in giving each student a fair program of observations through the telescope:—two studies of the Moon, of sun-spots, of Jupiter and of Saturn; one of Venus, Mars, the great Nebula in Orion, of Praesepe as a loose cluster, of the cluster near Alpha Cancri as an example of a close one; of the cluster in Hercules as a globular cluster; of Castor and Gamma Virginis as examples of double stars; and if possible of the spectrum of Sirius and Alpha Herculis.

Many students, who are enthusiastic and frequent the observatory, secure a good deal more in the way of observation, but there are not evenings in the year available, in an undergraduate program, to require more for the large number in the general course. (These articles do not consider the work of the smaller mathematical classes.)

By way of preparation for some of these observations, the familiar large chromo-lithographs from Trouvelot's drawings are in some cases useful. Students note by inspecting these what details must be identified at the telescope. For example, in the case of the Orion Nebula:—the four stars in the midst of a dark spot devoid of nebulosity, the five sided luminous so called "Huyghenian region", the dark rift "the fishes mouth" on the following side, the bridge of faint nebulosity which crosses it, and the "bats wing" extension upward. On fine evenings more difficult details are looked for, as the Herschel and Struve stars in the trapezium region. All the photographs of this region are displayed on the library tables:—the drawings of the old astronomers and Draper's first photograph in the Holden Monograph, Bond's drawings in the Harvard Annals, the photographs of different exposure in the Volume of Isaac Roberts and the unequalled one of Ritchie of Yerkes Observatory.

It is very desirable that while one demonstrator is at the telescope on observing evenings, another should be in the library, preparing the student for his observation and directing where to obtain from Ephemeris or other sources desirable data for the note book record.

In case of the Moon, the record should state the hour of observation and the Moon's age at that hour, it should contain a rough drawing in which the craters and seas specially observed are sketched in with their names from Colas' Map; in case

of Jupiter the positions of the moons should be sketched with their number and indication of the direction of their motion from the Ephemeris, also their approximate position on a diagrammatic outline of their orbits copied from the Ephemeris;* in case of Saturn, a drawing and tabulated record of what had been noted as to position of rings and shadows.

We give the laboratory time of at least two weeks to the Moon. The directions in the hands of students are as follows:—

STUDY OF PHOTOGRAPHS OF TYPICAL REGIONS OF THE MOON.

Material:—Colas' Map of the Moon,† and selected photographs‡ taken at different observatories.

Directions. 1. Prepare a circle for map projection with a radius of 75 millimeters (the largest circle convenient on the notebook sheet). Draw through the center two diameters at right angles to each other. Mark the top south, the bottom north, right hand east, left hand west. The map is to give the appearance of the Moon in an inverting telescope.

Lay off and mark with dots on the horizontal diameter from the center each way the following distances:—73, 70, 64, 57, 48, 37, 25, 12 millimeters. These are the points where the meridian for each ten degrees cuts the equatorial diameter. Draw them through these points and the north and south poles. This can be done fairly well by the eye on this small scale.¶

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* Students find much interest in determining for themselves the approximate periods of the moons of Jupiter from the prediction of their positions for the month pictured after the manner of Galileo in the Ephemeris. Opposite their estimates they record the exact periods to fractions of a second.

† Colas' Map of the Moon can be obtained of Poole Brothers, (Railroad Printers) Chicago. We use for divisions of twenty five of these maps mounted on easels.

‡ The photographs of the Moon offered by the Goodsell Observatory are excellent. We set up about twenty-five photographs from the Lick and Paris Atlases and from the Yerkes plates of nine different regions:—Crescent Moon, the two regions of the triple craters, the mountain region of the Alps and Apennines, the region of the pentagon of craters including Tycho and Clavius, the Copernicus region, Mare Humorum and Gassendi etc. Photographs are selected to show the same region at waxing and waning phase, and sometimes the same region taken successive days.

¶ The projections of these meridians are in reality ellipses with the vertical radius of the circle as the semi-major axis a, and as semi-minor axis b, distances measured on the horizontal diameter from the center, found by the formula $b = R \cos a$ (harmonic) where a is the number of degrees of longitude $10° 20° 30°$, or any other number. To find the positions of the foci of the ellipses on the vertical axis for exact drawing, first find the eccentricity $e = \frac{\sqrt{a^2 + b^2}}{a}$, then ae is the distance from the center to the foci north and south on the polar diameter.

2. From Colas' map sketch in the seas and print the names upon them.
3. Study each group of photographs, sketch in on the skeleton map the most striking features and record in notes the place where the photograph was taken, the Moon's age, the meridian near the terminator found from Colas' map, whether the phase was waxing or waning, names of the principal mountains from the key, remarks concerning shadows, ridges, white streaks. Compare all the photographs with critical notes.

A list of questions aids this detailed study of a fair fraction of the Moon's surface, and calls out from the student a summary of the characteristic features of the lunar surface, the differences of appearance at waxing and waning Moon, significance of shadows etc., also the students' own conclusions as to the slow rotation of the Moon and its period.

Study of the Solar Rotation and of Sun-Spot Zones.

Through the kindness of Fr. Hagen of the Georgetown Observatory we have several sets of Sestini's drawings of Sun-spots made some time ago and published by government.

A selected set of these giving the daily appearance of the Sun for ten days is laid out, and a circle the exact size of those in the drawings is made on tracing paper with the north point marked upon it. The circle is laid upon each of Sestini's drawings in turn and all the sun-spots are traced upon it. In the end there is a composite of the surface of the Sun for ten days, and on inspection in reply to a list of questions the student states his discovery of the Sun-spot zones, of the Sun's rotation and roughly of its period, of the differing persistence of spots, the path of the spot entirely across the disk, of the concavity of the path showing the approximate position of the Sun's pole, of the difference in the apparent daily progress of spots on the limb and near the center on account of the harmonic projection of these paths.

A special study of the Pleiades is made by giving out the coördinates of the principal stars taken from the Harvard Photometry. On one sheet of checked paper the stars are put in to a large scale (one centimeter, twenty seconds of right ascension in time beginning with $3^h\ 37^m$, and five millimeters, twenty seconds of declination in arc beginning at the lower right corner with 23°.) When this map of the cluster is completed, it is taken to the engraved chart of the Paris Observatory, copies of which are set up on easels and the characteristic nebulosity is sketched

in about the stars. Photographs are then studied and compared:—the one of Roberts taken with his twenty-one inch reflector, exposure four hours; the one of the Goodsell Observatory eight-inch refractor, exposure seven hours; and the one of the Yerkes Observatory twenty-four inch reflector, exposure three and one half hours.

The Argelander chart containing this cluster is shown and the stars identified on it, and later the spectrum plate of the Pleiades is laid over the chart, the stars identified and their type noted.

The method of measuring photographs in Astronomy, the effect of color on photographic magnitudes, the way in which plates are studied for the discovery of new objects is illustrated by studies of the exquisite plates* from Harvard Annals Volume XXVI.

The plates containing the southern cross, Omega Centauri, forty seven Tucanae—etc. are displayed. The objects are identified on the charts of the Uranometria Argentina and on the globe, the coördinates on the plate of designated objects are measured and recorded, the influence of length of exposure is noted.

Lectures amply illustrated by lantern slides† sometimes precede sometimes follow such studies furnishing at times a preparation and at times a review and test as to what has been accomplished.

The material and time available must decide in each case the work of this kind which a class can wisely do but the interest and value of it is without question, for in Astronomy as in Botany, Zoology, study of History of Art, the old saying is true:—"Sharpening the pencil sharpens the eyes."

Whitin Observatory, Wellesley College.

PHYSICS OF SHOOTING STARS.

J. F. LANNEAU.

FOR POPULAR ASTRONOMY.

Everyone is familiar with the suddenly bright, star-like objects which swiftly and silently dart here and there in the evening sky

* Photographs handled by many become soiled. Mr. Albert P. Morse of Wellesley Mass., has devised a method of interchangeable celuloid covers which are light and convenient and which protect plates it is hard to replace.

† Mr. H. Lawrence, Trinity Place, Boston, must be in possession of many fine negatives which he has taken for us from the volumes of Roberts, from the Tulse Hill Annals, and from Astronomical Journals. He could doubtless furnish slides.

every few minutes. These transient and seemingly erratic meteors are popularly known as shooting stars.

In Ptolemy's Almagest—written in the second century of our era, the authoritative text on astronomy for fourteen hundred years, taught once even in Harvard and Yale—there was no mention whatever of shooting stars. They were held to be mere exhalations from the earth—of no concern to an astronomer. But found to be truly celestial bodies, their study has become in recent years a specialty with some astronomers.

By physics of a shooting star is meant such facts as its height above the earth, its distance from the observer, its mass or weight, and other seemingly unattainable knowledge concerning it.

It is proposed to show in outline how such knowledge may be gained.

Height, Distance, Velocity.

Two observers—one say near Wake Forest and one thirty-five miles due south, near Selma—agree to watch the western sky

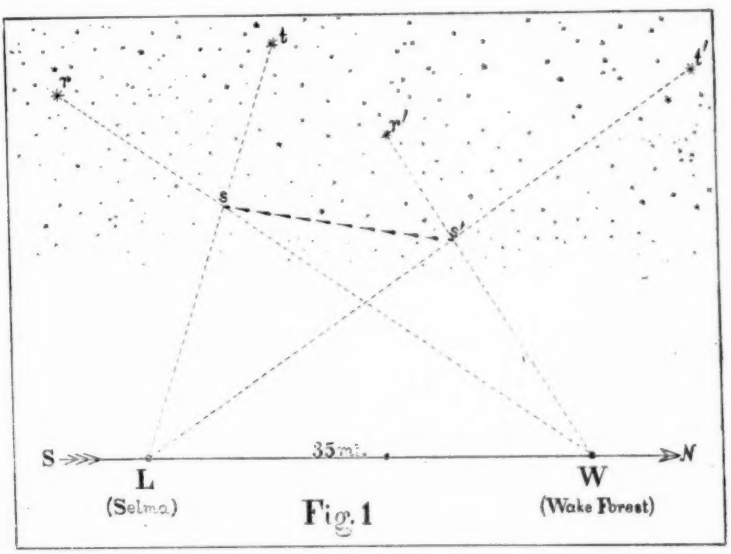


Fig. 1

every fair evening until nine o'clock. Many of the little meteors carefully noted by one of the watchers are not observed by the other.

One evening however, as subsequently shown by comparing

records, they both note the same shooting star seen to pass from the point s to the point s′, Fig. 1.

Each observer counts rapidly while it shoots from s to s′. At the same time he notices the particular fixed stars nearest in line with its appearance and disappearance at s and s′—the stars at r and r′ as seen from W, and the stars t and t′ as seen from L. This much quickly done, each looks at his watch to see the hour and minute of the occurence. Then, by several repetitions of his rapid count, watch in hand, he finds the number of seconds in the transit from s to s′.

Their records, say, are:

	—At L—		—At W—
Count	23; Time, 5½ sec.	Count	26; Time, 6½ sec.
From	Castor, (star beyond s)	From	α Hydræ, (star beyond s)
To	Capella, (star beyond s′)	To	Procyon, (star beyond s′)
Date	May 1 '05, 8:30 o'c. p.m.	Date	May 1 '05, 8:29 o'c. p. m.

The two sets of notes agree substantially, as they should, in the number of seconds of the shoot from s to s′ and in the hour and minute of the observations. They differ, of course, as to the stars in the lines of sight from stations thirty-five miles apart.

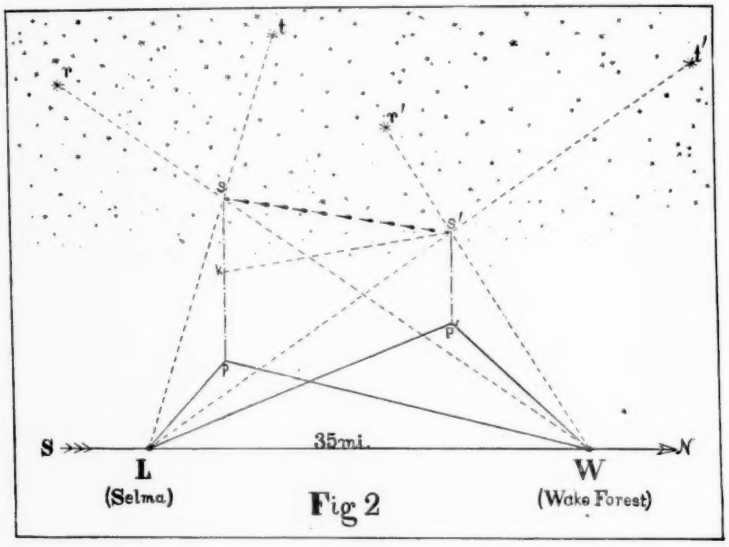


Fig 2

The averages of the time from s to s′ and of the time of observation, as noted, are taken as correct; 6 seconds as the time of transit and $8^h\ 29^m\ 30^s$ as the time of observation.

These simple observations are sufficient. The rest is matter of

calculation aided by data taken from the American Ephemeris, a government .publication based on the work of the National Observatory at Washington.

Skilful use of the data for Castor and Capella, α Hydræ and Procyon, gives the directions of those particular stars as seen from L and W at 29 minutes and 30 seconds past 8 o'clock on the evening of May 1; that is, the directions of s and s′ from L, and their directions from W.

In Fig. 2, p and p′ are points on the earth vertically under s and s′. The directions found by calculation as just stated, are: for s, its angles of elevation pLs and pWs, also its horizontal bearings, the angles pLS and pWS; and for s′ the like angles p′Ls′, p′Ws′. p′LS and p′WS. Obviously, this gives all the angles of each of the three triangles which meet at p and of the three which meet at p′. And since one side, LW, is 35 miles, all the other sides in each of the six triangles can be calculated.

We thus find ps the shooting star's height when first seen, Ws its distance from W and Ls its distance from L; also p′s′ its height at the moment of extinction, and Ws′ and Ls′ its distances at that moment from W and L.

The line s′k is drawn parallel to line p′p, omitted in the figure. Triangle p′pL gives the length of p′p and therefore of its equal s′k. Right triangle s′ks gives length of ss′. This length was traversed in six seconds. One-sixth of it is the shooting star's velocity per second.

Such observations and calculations show that usually a shooting star's height, when first visible is about 75 miles; and when it disappears, about 50 miles. Also, that its bright path extends 40 or 50 miles; and that its velocity ranges from 8 to 44 miles per second—indicating that its velocity through outer space, just before it entered our atmosphere, was about 26 miles per second. Its distance from the observer varies greatly, from 60 to 600 miles—possibly 770 miles.

The observed velocity is, of course, only relative to the earth. Its wide range, from 8 to 44 miles per second, is readily understood by considering Fig.3.

In this figure, the earth is represented turning eastward about its axis—N its north pole—and moving in its orbit eastward, the Sun being in the direction of S.

An observer at O has just passed into the evening shade. Relative to him, the earth's orbital motion, 18 miles per second, is *downward.* If he sees a nearly overhead shooting star it is overtaking the earth, and its velocity, relative to the earth, is

26 — 18 = 8 miles per second. An observer at O′ is soon to greet sun-rise. Relative to him, the earth is moving *upward* 18 miles per second. A shooting star above him is meeting the

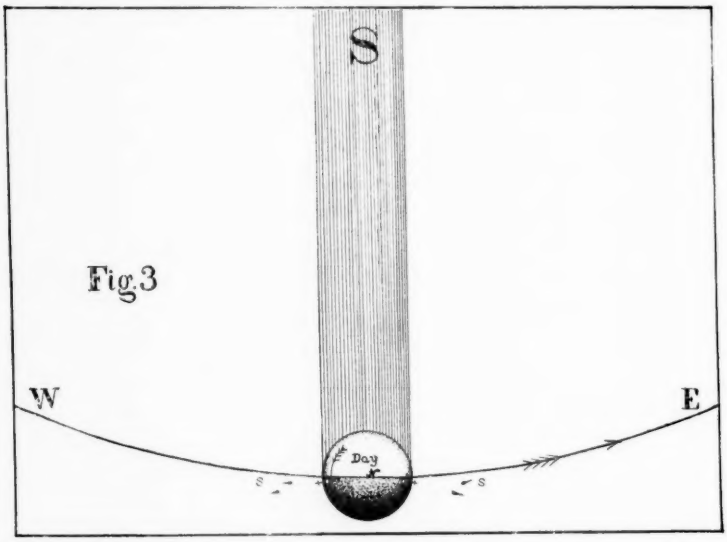


Fig. 3

earth, and its relative velocity is 26 + 18 = 44 miles per second. To either observer, a shooting star crossing the earth's path will show more nearly the average velocity.

A notable shower of shooting stars occurred on the 24th, of November 1892. It continued for three hours after 8 o'clock in the evening.

That periodical star shower—the Bielids—will occur again this November—in the evening of some country. It may occur during our evening hours. If so, notice the slow motion of the "falling" stars. Should the reader be privileged to see the next Leonid star-shower, expected in the early morning hours of Nov. 15, 1933, he will note the startling rapidity of the star-fall.

In general, the velocity of the evening shooting stars is less than 26 miles per second, and that of morning shooting stars is greater.

Moreover, as the earth speeds on in its orbit its front is the sun-rise side and its rear is ever in the evening shade. We therefore see more shooting stars in the early morning than in the

evening—just as in a walk or drive more people meet us than overtake us.

MASS OR WEIGHT.

To find a shooting star's weight requires the help of an assistant observer at one of the stations. When preparing for the observations at W and L, Fig. 1, suppose an incandescent lamp of 16 candle-power was placed at an elevation above a high hill west of W, plainly visible to the assistant at W and distant from him just one half mile.

The assistant does one thing only. He compares the brightness of the lamp high up in the west with the brightness of each shooting star noted, and in each instance records his judgment as to the relative brightness of star and lamp. Of this he soon judges quickly and correctly, especially when the flitting star and the distant light are about equally bright. Even an unpractised eye decides readily which of two nearly equal lights is the brighter. Of hundreds asked by the writer which of the twin stars, Castor and Pollux, is the brighter, not one decided incorrectly.

Say that to the notes of Fig. 1 the assistant at W added: "brightness of shooting star and incandescent lamp just equal;" also, that the calculations of Fig. 2 proved that the shooting star's average distance from W was 60 miles. This data-distance of lamp, distance of star, their equal brightness—and established principles of Physics, will give the shooting star's mass or weight.

Since to make a one candle-power light requires 150 foot-pounds of work or energy per minute, the 16 candle-power light on the hill was produced by 16 times 150 ft.-lbs. of energy per minute, or by $^1/_{10}$ of 16 times 150 ft.-lbs. of energy every 6 seconds; that is, it was made by using every 6 seconds 240 ft.-lbs. of energy.

The shooting star 60 miles off and shining 6 seconds, as observed, was just the brightness of the 16 candle-power light ½ mile away.

The intensities of two such lights—lights equally bright at different distances—are as the squares of the distances. In this instance then, their intensities were as 60^2 to $(\frac{1}{2})^2$, or as 14400 to 1. That is, the energy which produced the shooting star's brightness was 14400 times 240 ft.-lbs. = 3456000 ft.-lbs of energy.

For a body in motion, the established relation between its weight expressed in pounds, its energy in foot-pounds and its velocity in feet per second is $W = 64\frac{1}{3}\,\frac{E}{V^2}$. So the weight of our shooting star was $64\frac{1}{3}\,\frac{3456000}{(26\times 5280)^2} = \frac{1}{84}$ lb. $= \frac{1}{5}$ oz.

Not infrequently a meteor weighing many pounds reaches the earth's surface—as claimed for the black stone enshrined in the Kaaba at Mecca. But the usual shooting star which is dissipated in the air, is a light body—in many instances not more than a grain in weight.

Cause of Sudden Brightness and Quick Extinction.

When a moving body is checked, or stopped, its seemingly lost energy instantly reappears as heat.

The simple clapping of hands—repeated checking of motion—heats them. A piece of iron on an anvil hammered sufficiently, becomes red hot. Visitors to the Chicago exposition in 1893 recall the muscular Samoan who, astride a dry log, so vigorously rubbed the end of a stout stick back and forth along a shallow groove in the log that soon it was ablaze!

Mechanical energy checked, is converted into heat at the rate of 772 ft.-lbs. of energy to one heat unit. The heat which raises the temperature of a pound of water one degree Fahrenheit is taken as a unit of heat.

The air's resistance checked and soon stopped our shooting star's swift motion, converting its astonishing amount of energy, 3456000 ft.-lbs., into a correspondingly large quantity of heat, 4477 units. This much heat would make a half-gallon of ice-cold water boil—and boil away as steam! Its self-evolved heat raised the substance of the shooting star to incandescence—caused its sudden brightness. Did it melt and vaporize the matter of the little meteor? Let us see. Had its weight been 84 times greater —a full pound— and its substance solid platinum, one of the most refractory of metals, it would have been melted by only 49 units of heat—provided the temperature was as high as 3230° Fahrenheit.

Experiment shows that when a body speeds through air 125 feet per second its temperature rises 1°. If its velocity is doubled, its temperature rises 4°; if trebled, 9°. That is, the number of degrees rise of temperature is the square of the times the velocity contains 125 feet.

Allowing that our shooting star was one of the slowest, its velocity only 8 miles per second, its temperature was raised $\left(\frac{8 \times 5280}{125}\right)^2 = 11419°$; more than three times the temperature at which even platinum melts.

It seems therefore, that whatever the shooting star's substance it is quickly raised to glowing heat; that if solid it is soon melted

and vaporized—the melted matter being swept off by the rush through the air, forming the luminous train until none is left, when comes its sudden extinction. Its cooled vapors and ashes mingle with the air, and the dust-like débris slowly settles to the earth's surface.

Number Daily.

Simple means will serve to effect a fairly accurate count of the number of shooting stars visible at a given place during a definite period.

At a selected station in an open space erect a pole 6 feet high. Trace from it on the ground two lines diverging 45°—half a right angle. On each line, at a distance of 6 ft. from the pole, drive a stake. Connect these stakes by a stout string 3½ ft. above the ground, and from each stake, at that height, stretch a string to the top of the pole.

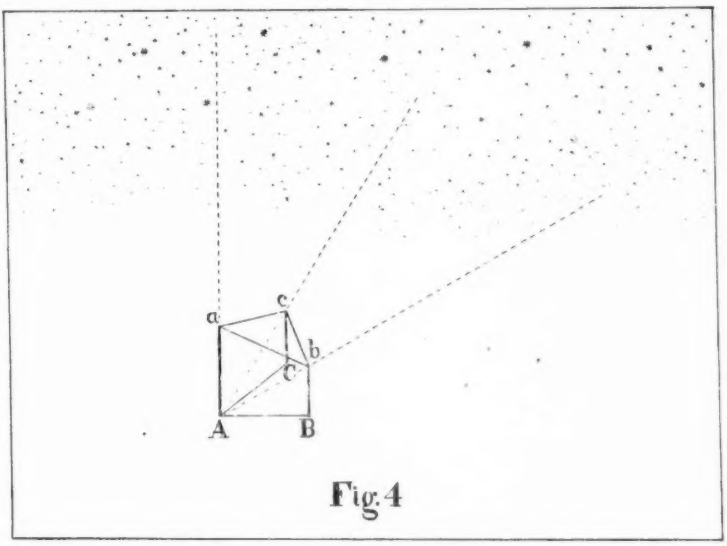


Fig. 4

In Fig. 4, A is the station, Aa the pole. At distances and heights stated, the stakes Bb and Cc are connected by string bc; and strings stretch from a to b and from a to c.

An observer, full length on the ground, his head at A and feet toward the stakes, scanning at his ease that part of the sky which appears within the triangle of strings, abc, will see just

one-eighth of all the clear sky above the hazy zone around the horizon 30° high. Eight observers so placed about A, each watching only the part of the sky marked off by his triangle of strings, would see all the shooting stars that appear in the clear sky while they watch.

On a fair evening it is found that each such observer sees a shooting star about every four minutes, or an average of 16 per hour. Eight observers see 128 shooting stars per hour. Thus through the upper air surface—all of it that is above the 30° belt around the horizon—there must enter daily 24 times 128 shooting stars, or 3072 per day.

Fig. 5 will serve to show the full significance of this result—that 3072 shooting stars enter daily the limited air space which our eight observers watch only a few hours.

In this figure the earth's radius OA = 3959 miles. The arc ezb indicates the level of air surface in which shooting stars first

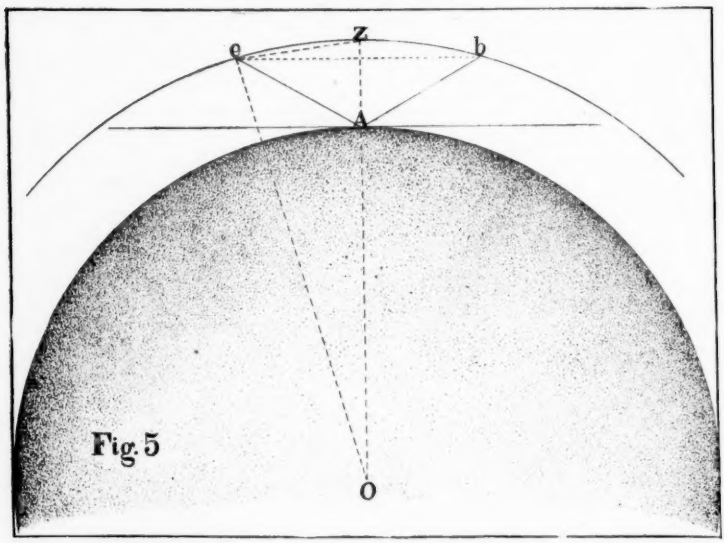


Fig. 5

appear. Let us call it the surface of apparition. As previously shown, the height Az = 75 miles. Our eight observers, flat on the ground, have their heads about the pole at A. Their lowest line of sight Ab, or Ae, is elevated 30°. Therefore angle zAe = 60°. During their vigils they see all shooting stars that enter the zone of apparition capping the funnel shaped space eAb.

We must compute the area of that zone. The upper edge or rim of the funnel is a circle whose diameter is eb. The zone watched is that part of the air surface cut off by a horizontal plane through eb. It is called a zone of one base, and its area equals a circle whose radius is the distance ze. We must find that distance. In triangle eOA, angle at A being known, also the sides OA and Oe, we find eOA, or eOz = 1° 47′ 47″. In triangle eOz, knowing angle eOz and sides Oe and Oz, we find ze = 126¾ miles. A circle of this radius contains 50462 square miles. The watched zone of apparition then covers 50462 square miles.

How many times larger than that zone is the entire surface of apparition which envelopes the earth at a height of 75 miles? Its radius Oz = 3959 + 75 = 4034 miles. Its area therefore, is over 204 million square miles. This is fully 4052 times 50462 square miles. That is, the area of the entire surface of apparition is 4052 times the area of the zone through which, as we have seen, enter daily 3072 shooting stars. Therefore, into the entire atmosphere enveloping the world there enter daily at least 4052 times 3072 shooting stars—in round numbers, 12½ million.

But had our eight observers held their vigils in the early morning before dawn, they would have counted more than double as many shooting stars per hour—indicating some 28 million per day.

Average the evening and the morning counts, and we find that the number of shooting stars which plunge into our atmosphere daily is fully 20 million.

Distribution.

The earth with its air envelope to a height of 75 miles, or simply the whole surface of apparition, is a globe whose radius is 4034 miles. The space through which it speeds daily 18½ miles per second, is more than 1½ million miles long. Its cross section, a circle whose radius = 4034 miles, has an area of more than 50 million square miles. This long cylindrical space through which we sweep daily contains more than 1½ million × 50 million = 75 million million cubic miles. More accurately it is over 80 million million cubic miles. Since in this space we touch 20 million little masses, to each one there is a space of 4 million cubic miles. Each little mass, a shooting star when it enters our air, has around it 4 million cubic miles of free space. In general, it is at the center of a cube of space each edge of which is about 160 miles long. From center to center of such spaces is 160 miles.

We thus find that throughout the space traversed by our earth

in its journey around the Sun embryo shooting stars, while always in motion, are distributed at intervals of about 160 miles.

Origin.

Comets move in planes which all pass through the Sun, but cut each other at all angles. They therefore move through space in all conceivable directions. When nearing the Sun their volatile matter is driven off in streaming tails of great length, and much of it, disrupted and scattered, lost to the parent body, pursues at intervals approximately the same general path as formerly.

Not a few comets pass close by the earth's orbit, crossing it at different points and at different angles. Some of these, as in the well known case of Biela's comet, have been shattered by disintegrating forces. They have ceased to appear as comets. In their stead, when due, are showers of shooting stars—the débris of the disrupted comets. That part of the passing débris swarm which enters our atmosphere is checked by the air's resistance, as was shown, and falls to the earth. The rest passes by until, on another round, it again grazes us, and is again diminished by another star-shower.

This doubtless is the origin of shooting stars which come in showers—like the Bielids every thirteen years, and the Leonids at intervals of thirty three and a third years—also of stragglers which, like the August Perseids, come annually.

Possibly, in the débris of shattered and shattering comets we have the origin of all shooting stars.

Effects.

We have seen that a shooting star weighing $^1/_{84}$ of a pound is dissipated by its self-evolved heat, that its vapors mingle with the air and its ashes settle to the earth.

Our world is thereby made $^1/_{84}$ of a pound heavier!

Take this as an average, and the 20 million shooting stars per day make the earth 125 tons heavier. This daily addition amounts to 45000 tons yearly.

How much will this increase the earth's size? Allow that all this meteoric matter, 45000 tons annually, finally settles to the earth's surface in a continuous layer of uniform depth; and that, like some common earth, a cubic foot of it weighs 80 pounds. Having the earth's radius, 3959 miles, we find its surface area is more than 5000 million million square feet. If covered with meteoric matter one inch deep, the weight on each square foot would be $^1/_{12}$ of 80 pounds = $6\frac{2}{3}$ pounds. On the entire surface

there would rest a weight of 33⅓ thousand million pounds, or 16⅔ million million tons. This is 370 million times 45000 tons, the yearly deposit.

That is, in 370 million years this accumulating shooting star dust will form on the earth's surface a layer one inch deep!

That 45000 tons of matter added to our earth every year for 370 million years would raise the level of its surface only one inch, may well expand our conception of the vastness of our earth.

We have seen, too, that one shooting star evolved 4477 units of heat. At that rate, 20 million daily bring us over 89½ thousand million heat units, and in a year, over 32 million million units of heat.

Uniformly distributed, how much heat is this to each of the 5000 million million square feet of the earth's surface?

Evidently, to each square foot only $\frac{32}{5000} = \frac{6^2/_5}{1000}$ of a heat unit.

Contrast this with the heat we receive from the Sun. Skillful experiments prove that the Sun sends to each square foot of the earth's surface on which it shines an average of 11 heat units per minute, or $\frac{11}{60} = \frac{110}{600}$ of a unit per second, or $\frac{110}{6000} = \frac{18\frac{1}{3}}{1000}$ of a heat unit in $^1/_{10}$ of a second. That is, we receive from the Sun in $^1/_{10}$ of a second nearly three times as much heat as is brought to us by myriads of intensely heated shooting stars in an entire year! The contrast serves to quicken our realization of the Sun's dominance in the support of terrestrial life by its constant, incomparable yield of heat.

SOME UNUSUAL DISCOVERIES OF VARIABLE STARS AT HARVARD OBSERVATORY.

GRACE AGNES THOMPSON.

FOR POPULAR ASTRONOMY.

Although it has long been recognized by astronomers that an investigation of the nebulous regions of the sky would yield much useful information, owing to the great amount of work already in progress at Harvard Observatory, a special detailed study of such regions for the detection of variable stars was begun there only during the past year. Except the Great Nebula of Orion which has been the subject of careful study with observers for years, and the Large and Small Magellanic Clouds,

almost nothing was known of existing conditions in such regions prior to this beginning. The number of variables that had thus far been discovered by astronomers was about 1500, of which about 970 were found at Harvard since 1890. About 200 of these were discovered by Mrs. W. P. Fleming, Curator of Astronomical Photographs, from photographs of their spectra; about 500 others by Professor Solon I. Bailey of the Arequipa Station of Harvard Observatory, through examinations of star clusters. The signal success of this examination has established another fact, that certain regions of the sky are distinguished by the presence of large numbers of variable stars. It also awakened fresh interest in a subject that has always been most fascinating, by demonstrating the infinite possibilities of research in this direction.

To the reader who has never been initiated into the mysteries of astronomy, the term *variable stars* must be as puzzling as their curious phenomena have always been to astronomers. Hundreds of years ago it was known that a few stars were subject to changes in brightness, the length and regularity of these fluctuations being determined by no fixed law. It may, in fact, be regarded as probable that all the stars are so changing, either growing brighter and hotter or fainter and cooler; but in the case of most of them the change is so slow or so slight that the oldest records and charts are not old enough to prove it. Technically speaking, variable stars are divided into five classes according to the length and type of their variations. They include: novae, or stars which blaze up suddenly where no star has before appeared, have a peculiar spectrum, and gradually fade away and are lost; stars which vary in a long period of from six months to two years or more, rising continuously from very faint to a brightness several magnitudes above this and then regularly fading out again, called long-period variables; those which vary in short periods of a few days and are constantly fluctuating in light; those which vary in short periods, but with great regularity, so that their maxima and minima may be predicted with an exactness that counts tenths of a second; those which remain at their maxima during the greater part of the time but at certain intervals diminish rapidly, remain faint for a brief time, and then increase as rapidly, often changing one or two magnitudes in a few hours. The last are known as Algol variables. All variables of short period are usually white or bluish stars. The long-period variables, on the other hand, are generally reddish in color, on which account their differences in brightness are often hard to

estimate visually; they also have usually spectra of the third or fourth type.

The actual causes of variation in these stars is not known. Various and numerous theories have been offered. But only one fact has been established: that the origin of fluctuation in the long-period variable is due to changes in the physical condition of the star. The variation of most short-period variables is due to causes that have not yet been determined, though it is probably the result of some peculiarity in their formation, made apparent by their rotation. Such stars have, no doubt, one side dark and the other bright. Stars of the Algol type are made to vary in light by purely mechanical action, probably from the revolution of dark bodies around them. This probability, which is now almost established as a fact, suggests a means of gaining some very interesting information, since it is thus possible to estimate accurately the times of revolution of such bodies, even though they are entirely invisible. Algol variables are named from Algol, the star of the same type, which with Mira, the star still recognized as the typical variable of long period, were the only stars whose variation had been certainly ascertained prior to the seventeenth century.

In 1901 and again in 1903, Professor Max Wolf of Heidelberg compared several of his photographs by means of stereo-comparators, the small stereoscopic instruments which have proved so important a factor in astronomical work, and of which an interesting description was recently given in Collier's Weekly by Garrett P. Serviss. Professor Wolf thus found and announced 33 variables in the neighborhood of Orion. But until the present investigation was instituted at Harvard, they do not appear to have been confirmed by other observers, and final designations had not yet been assigned to them; for the faintness of many of these stars even at maximum renders it probable that few photographs exist on which they can be followed. Professor Edward C. Pickering, Director of the Harvard College Observatory, already deeply and for a long time interested in this subject and aware that an unusual harvest of scientific fact might be gathered from a thorough and detailed study of variable stars, which he believed would be found to occur in large numbers in the nebulous regions of the sky, was most anxious to undertake such a systematic investigation at Harvard without delay. A grant made by the Carnegie Institution for 1903, permitted a large amount of work of this kind to be undertaken at Cambridge, and furnished a corps of eight observers for the study of the

Harvard photographs. But the failure to continue this grant for 1904 rendered it necessary to disband this corps and since December, 1903, similar work has been carried on at the expense of the Observatory by one investigator only, Miss Henrietta S. Leavitt, who began her present investigations during the latter part of February, 1904. A number of photographs of the Nebula of Orion are contained in the Harvard collection, and a careful examination of them was made by Miss Leavitt early last year. Besides confirming 18 of Wolf's variables, she thus found 72 new ones in this one nebula, varying between the eleventh and the fifteenth magnitudes. Within the limits of a part of Professor Bond's map of Orion and its neighborhood, in a region covering 6885 square minutes of arc, out of 1100 stars examined, 65 were found to be certainly variable and 18 others were suspected af variability. It is a curious fact that these stars are found within and following the denser distribution of the nebula. The plates for this examination were superposed successively upon a glass positive made from one of them, after the method followed in such investigations at Harvard. It is possible that many other variables will be discovered in this region, when more photographs become available for comparison, as many of those found appear to remain at their minimum magnitude during a large part of the time.

In no respect have the results of photography been more striking than in the revelation of diffused nebulae of vast extent, whose faintness renders them almost beyond the reach of visual observation. One of the most remarkable of these extends over many square degrees in the constellations of Scorpius and Ophiuchus. Like the Nebula of Orion, it attaches itself to individual stars, the principal condensation being about the quadruple star, ρ Ophiuchi. The region is marked by a noticeable absence of stars of the fainter magnitudes and dark lanes can be traced in different directions for a considerable distance beyond the visible nebulosity. A cursory examination of a part of this region has led to the discovery of 72 new variable stars, besides the eight already known.

In the Trifid Nebula in Sagittarius, which is near the center of a large number of the photographs taken for the study of Phoebe, the ninth Satellite of Saturn, discovered by Professor William H. Pickering in 1899, a careful search for variables was made by Miss Leavitt during the latter of 1904. From the examination of seventeen plates taken with the 24-inch Bruce telescope and having exposures of from one to three hours, there seems to be

no evidence that variable stars are present in large numbers in this region. Only 16 were found. A little earlier in the year, however, in the course of an examination of plates in the region of Sagittarius, a very interesting variable of the Algol type was discovered. Over 300 plates were available for the study of the new object, on 28 of which it is fainter than the normal brightness, magnitude 9.55. In three cases it appears faint on two plates taken during the same night, so that twenty-five different minima have been observed. The observations indicate that the period is about 3.45 days, with a range of about one magnitude. An interesting and unusual feature in the variation is found in the fact that a secondary minimum occurs midway between the primary minima, and is about three tenths of a magnitude fainter than the normal brightness.

The most fruitful field, however, that has been examined is the Small Magellanic Cloud, where up to the present time 900 variable stars have been discovered, and 64 others suspected of variability. On one plate of this region, covering a portion of the sky six by seven degrees in area, Miss Leavitt found more than 400 variables. The Large and Small Magellanic Clouds* are two of the most interesting objects in the sky, and were on this account the first regions after Orion examined last year. In a circular issued by Harvard Observatory May 26, 1904, announcement was made of the discovery of 57 new variable stars in the Small Magellanic Cloud. In order to provide material for the study of the light curves of these stars, sixteen excellent photographs, having exposures of from two to four hours, were taken last Autumn at Arequipa, with the 24-inch Bruce Telescope. These plates reached Cambridge in January of the present year, and an examination of them by Miss Leavitt led to the surprising discovery that hundreds of variable stars were present in this region, the small number found in her earlier examination being due to the unsatisfactory quality of many of the plates. The determination of the positions, elements, and light curves of this large number of variables is now in progress, and will be published in the Annals of the Observatory as soon as it is completed.

Nearly all the variables are found strictly within the limits of the Small Magellanic Cloud. Few have been found at a greater distance than a degree and a half from the center, excepting in the clusters 47 Tucanae and N. G. C. 362. The more sharply defined limits of the preceding side of the region are seen also in

* See Frontispiece.

the distribution of the variables. To study this, the region of about six by seven degrees, covered by the plates has been divided into squares which measure approximately half a degree on a side. The center adopted is not far from the center of the Cloud, which extends diagonally in a direction from north-east to south-west. The limits of the region containing the variables are more sharply defined, and are closer to the central line of the most densely crowded portion on the preceding than on the following side.

Several examples of variability are shown in Figures 1 and 2, which are enlarged six times from the original photographs. The area represented is 12′ square. Figure 1 is an enlargement

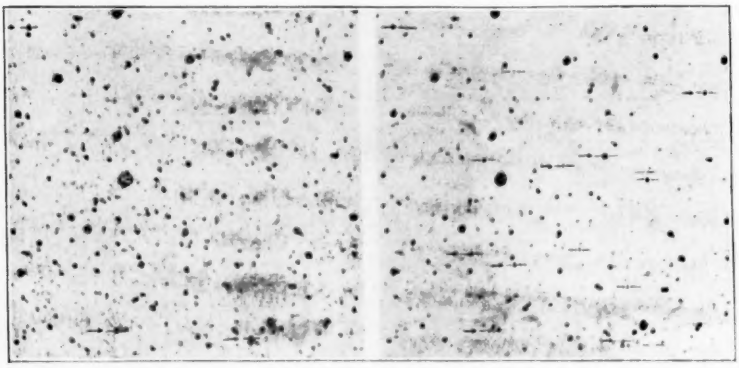


FIG. 1. FIG. 2.

from Plate A3393, taken November 10, 1898, exposure 300 minutes, and Figure 2 is from Plate A6981, taken September 30, 1904, exposure 240 minutes. All the variables in the region are marked on the latter, while on the former three stars are marked of which the changes are well seen on this pair of plates. According to a scale used last year, the two conspicuous variables in the lower half of the region show a variation of about 1.2 magnitudes each, while that of the third is about a magnitude. Variables which show little change on this pair of plates, are well seen on others. There are many other regions, of equal interest. No catalogue stars are contained in these regions, as even the brightest are too faint to appear in the Cape Photographic Durchmusterung. The number of stars shown in the photographs, in the central portion of the region, is about thirteen to a square minute of arc, or 46,800 to a square degree. It is

estimated that a number of stars photographed in the Small Magellanic Cloud and adjacent clusters is about 280,000, of which 910, or one in 308, is variable. In the surrounding region about 40,000 stars appear on the best negatives, of which 12, or only one in 3,300, has been found to be variable, although all have been examined with equal care. The region shown in the figures covers 144 square minutes, and includes at least 1272 stars, of which 755 may be called conspicuous. It is very difficult to count the faint stars which cloud the background, on account of their closeness to one another, and the number is certainly underestimated. Few of the variables have been observed to become as faint as these stars. The figures cover about one thousandth of the entire region, which if shown upon the same scale would occupy seven by eight and a half feet.

A careful examination of the Looped Nebula in the Large Magellanic Cloud last year yielded quite a different result. Out of 867 star images examined, two were suspected of slight variability. At present it seems likely that the large Magellanic Cloud contains but few variables, which, if true, would be a curious fact, since it is so similar to the Small Magellanic Cloud in formation. Both these regions, it may be interesting to note just here, were probably at one time a great southern arm of the Milky Way which they closely resemble in formation, though it is evident that they are not in any way at present connected with it. They are situated at a considerable distance from this great belt near the south pole, and are therefore not visible to observers in the northern hemisphere. The cloud-like appearance of both these phenomena is produced by the confused light of a vast multitude of individual stars massed together; like the Milky Way, also, the Magellanic Clouds are distinguished by the presence of stars of the fifth type, and by nebulous matter, much of which is too faint to appear on photographs taken with any but the most powerful telescopes.

The results of this great scientific undertaking at Harvard have been thus far very gratifying to Professor Pickering. In a little more than one year the number of known variables has been almost doubled, and a great deal of interesting and important information secured. One of the most interesting facts established is the great and often surprising dissimilarity of different nebulae. In the beautiful cluster of the Pleiades, for instance, which is nebulous, and where one might expect to find an especially large number of such stars, no cases of variation whatever have yet been found. In the nebula surrounding

η Carinae, considered by many the finest nebula in the sky after Orion, very few variable stars have been found. The facts as they exist at present render such regions doubly interesting, since they illustrate how impossible it is to deduce any rule that will govern all nebulous regions alike. Even with regard to the type of variation found in the various nebulae there is little similarity. Each nebula is a law unto itself.

The total number of variable stars that have been discovered by Miss Leavitt since she began her investigations in February, 1904, to the date of writing this paper is approximately 1300. Yet the work is hardly more than well begun, for the collection of photographs at Harvard includes nearly 200,000 glass plates, giving an exhaustive history of the sky during the past sixteen years, and of the more interesting regions since 1883. Not only then must the majority of these photographs be carefully examined, but as new plates are constantly being taken at both the Harvard stations at Cambridge and Arequipa, fresh work is constantly being added. Moreover, besides additional plates of nebulae already known, new nebulae too faint to be detected on photographs taken with the smaller instruments, will doubtless be made apparent by means of the large reflectors now being mounted at Harvard and elsewhere, and it is probable that these future plates will show large numbers of stars of the very faint magnitudes, and that among them will be found many cases of variation.

A discussion of this examination and of the work entailed by it would not be complete without some mention also of its effect upon another department of the research at Harvard. A complete bibliography of all the variable stars then known was begun there by Professor W. M. Reed, when he was connected with the institution some years ago. This work was resumed in September, 1900, and has since been continued by Miss Annie J. Cannon, so that there are now more than 35,000 cards. A minute record of every observation of each star in the series is thus kept, with the name of the observer, the observatory and instrument, as well as the technical description of the star, its position, period of variability and dates of maximum and minimum. Not merely therefore is the present study of nebulous regions adding a long list of variables to those already known, which in itself would be simply an interesting event in the course of scientific progress, but it will furnish an amount of detailed information concerning them, which will prove of inestimable value to astronomers and to others who are interested in the science.

Cambridge, Mass.

ON THE OBSERVATION OF VARIABLE STARS.

PAUL S. YENDELL.

I

The Argelander Method.

For Popular Astronomy.

The observation of the variable stars is a branch of astrophysical work which recommends itself particularly to amateurs from the fact that no expensive instrumental equipment and no special mathematical training are necessary for its successful pursuit. A small telescope, such as is already in the hands of many an amateur who would be glad to know how to turn it to some practical purpose, is sufficient for the observation of a large proportion of all the known cases of variability, and to furnish useful employment for as much of its possessor's spare time as the latter may care to devote to such purposes.

In the absence of a telescope, a large number of variables may be watched through all their changes with the aid of a field or opera-glass, and some with the unassisted eye.

There is an idea current that the old "naked-eye" method, as the workers with the photograph and photometer call it, is obsolete and inaccurate, and that without one or other of these adjuncts the observer cannot hope to add useful material to the growing mass of information on the subject.

The error of this impression is evident from the fact that in photometric work, the results depend on the decision of the eye on the question of the equality of images, while in the photographic method, the size of the star-images measured is necessarily affected to a varying degree by the colors of the stars themselves, and probably by the atmospheric conditions under which the plates are exposed. A comparison of the probable errors of observation also indicates that the relative accuracy of the Argelander method is much greater than is supposed by many.

A large part of the work in this direction is done by amateurs, of whom many are contributing new discoveries to the list of known variables; the names of Roberts, Anderson, and Williams will sound familiar to the readers of Popular Astronomy; neither of these gentlemen is an astronomer by profession, one being a clergyman, and the other two civil engineers, with which latter profession the writer has the honor of being connected. Mr.

Anderson has probably discovered more telescopic variables by the "naked-eye" method than any other observer, and I know of none of his discoveries that has failed of confirmation.

Another advantage of this work is, that it can be carried on anywhere that a clear view of the sky, undisturbed by extraneous lights, may be had. I know of one case of a well-known variable, the question of whose variability was finally settled in the mind of its discoverer by an observation obtained from the platform of a railway car as the train stopped at a station. Windows also make good observing places. For four years, the writer's observatory consisted of his back yard and front steps; and during the past year he has made many observations of suspected stars from the latter point.

Argelander habitually did his variable-star work in the garden of his observatory, when the use of the telescope was not necessary. Sawyer has never, I believe, had a regular observatory, neither have many others whose names are well and favorably known to their fellow-workers in this branch of astrophysics.

In short, all that is necessary to do much good work, and to contribute much useful and valuable information to our stock of knowledge is an opera or field-glass, and a stock of good -will and patience—the latter especially, for the stars never hurry.

The method of observing most available to the amateur is that devised by Argelander, and known by his name, as the Argelander method. It rests on the ability of the eye to distinguish and estimate small differences in brightness between two stars. When these differences are large, it is beyond the power of the eye to estimate them with any degree of accuracy, but differences of two or three tenths of a magnitude can be estimated and compared with very considerable precision and it is upon this capacity of the eye and mind that the system of "step-comparisons" on which the Argelander method rests is founded.

The "step", or "grade" as it is called by some observers (the terms are etymologically identical) is the smallest difference in light which can be perceived with certainty upon comparing two stars and this is made use of as the unit of our numerical scale. We find, by experience that the average value of the step is about one-tenth of a magnitude though this is found to vary with different observers, and in different series of observations by the same observer. This, however, is not important, as it is always easy to determine the equivalent in magnitudes of our "step-scale", as will be shown hereafter. The step generally remains pretty constant with the same star and series of comparison-stars.

Chandler's description of the method, published in 1887, cannot be surpassed for clearness and brevity, and I therefore quote it here in its original words.

"In comparing two neighboring stars with each other, if after glancing back and forth from one to the other several times in succession, no difference appears, they may be considered of equal brightness, and the observation may be recorded by writing the symbols denoting them in juxtaposition. Thus, if we are comparing the stars *a* and *b*, we may write *ab* or *ba*

ab or *ba*,

which denotes equality, it being indifferent which letter is given precedence. If however, the stars appear at first equal, but on attentive consideration, and by repeatedly glancing from *a* to *b*, and from *b* to *a*, *a* is judged either always or with few exceptions, to be brighter, although only by a scarcely perceptible difference, Argelander calls *a* 1 step brighter than *b*, and records the observation thus:

*a*1*b*

If, on the contrary, *b* appears the brighter, the observation is to be written

*b*1*a*

If one star appears always or undoubtedly brighter, though still by an excessively small difference, this is called 2 steps, and the observation is recorded

*a*2*b* or *b*2*a*

according as *a* or *b* is the brighter.

A little more decided difference of light, one which is perceptible at first glance, will be denoted as 3 steps, and so on.

Although the above definition of the value of a step and the differences of light corresponding to its multiples, may appear vague and unsatisfactory to those unfamiliar with the subject, it will be found, after a little practice in observation, that when a notion is acquired of the smallest difference perceptible to the eye—which constitutes the unit of measurement, and which, of course is different in different individuals—the mind attaches a pretty definite conception to what constitutes twice or thrice that amount, and is enabled to construct a uniform scale, 0, 1, 2, 3, and 4 steps, for use in the measurement of these small light-differences. Differences of more than 4 steps it is not practicable to estimate with any certainty.

A clearer idea of the meaning to be attached to the step-unit, and one more easily applied in observation, may be obtained as follows. When a difference is perceptible between the brightness

of two stars *a* and *b*, but so small that it is not possible to imagine a star between them, and different from either in brightness, the difference of *a* and *b* may be called *one step*. When it is possible to imagine a star between *a* and *b* in brightness, the difference of *a* and *b* may be called *two steps*. When it is possible to imagine two stars between *a* and *b*, different in brightness from either of them and from each other, the difference of *a* and *b* may be called *three steps*, and so on.

From the above, it will be seen that the fundamental unit, the step, in this method of estimating light-differences, is entirely arbitrary. Experience has shown that it corresponds to about ten per cent of the brightness of the stars compared—for some eyes more, and some less; and also, that it retains a nearly fixed value for a given individual and series of observations. What this value is, in any case, is of no consequence whatever for the ordinary purposes of variable-star observations, as will be seen when we come to describe the mode of its employment."

To apply the principles above laid down, the first thing to do is to select a series of comparison stars. These should be chosen in the neighborhood of the variable, and should form a series of different brightnesses, from a little brighter than the variable at its maximum to a little fainter than its minimum brightness; the intermediate stars should be of various degrees of brightness, forming a series with intervals if possible of not more than four or five steps; two or three steps are preferable, but such as are not always to be had. They should be chosen within convenient distance of the variable, and not too near bright stars. If the variable is a well known one, it is advisable to use the comparison-stars and notation used by former observers rather than to select new ones, for obvious reasons.

At each observation, the variable should be compared with as many of these comparison-stars as do not differ from it more than four or five steps, some brighter and some fainter, but at least with one brighter and one fainter. Observations which depend upon comparisons with stars which are all brighter or all fainter than the variable are very uncertain; the more equal the distribution in this respect, the more thoroughly will the errors in the step-values be eliminated. In each comparison the number of steps corresponding to the observed differences of light should be observed and recorded according to the method above described. If the observer is uncertain in any case which of two successive step differences to record, the observation should be recorded in such a manner as to make this fact plain; thus

$a2 - 3b$ or $a2\ \frac{1}{2}\ b$

will indicate that *a* is estimated as more than two steps, but less than three steps, brighter than *b*.

Never, if it is possible to avoid it, be satisfied with a comparison with a single star; such observations are necessarily uncertain, and the practice is always a vicious one. This is the unanimous opinion of all experienced observers. Argelander was in the habit of using three or four comparison-stars at each observation, and often five; there are few examples of only two being used, and still fewer of single-star comparisons, in his published observations.

This mode of observation may be varied to some advantage by estimating not only the step-intervals of the variable from a brighter and a fainter comparison star, but also their relative proportion to the whole interval between the two comparison-stars. It is convenient to put this in the form of tenths of the whole, thus

a 3 *v* 7 *b*

indicates that *v* (the variable, usually thus designated) was estimated to be three-tenths of the whole interval between *a* and *b*, fainter than *a*, and seven-tenths of the same interval brighter than *b*. Given the magnitudes of *a* and *b*, the reduction of this estimate to magnitudes is simple.

This serves as an excellent check on the step-estimate, for although the two observations are not independent of each other, there is no doubt that the use of both forms of estimate renders the observation more accurate.

"It is hardly necessary to say," says Chandler, "that the briefest and most convenient notation for the comparison-stars is to denote each by a letter of the alphabet. In the case of the naked-eye variables, Bayer's letters will of course be the most appropriate, where his stars are used. Flamsteed's numbers, and indeed any numerical notation, should be avoided, on account of liability to confusion and mistake in the record; but, if employed, the numbers should be placed in brackets, to distinguish them from the numbers denoting the light-differences." The writer would say, that use of bracketed numbers in recording variable-star observations is in practice a very clumsy and puzzling method, considering the circumstances under which the record commonly has to be made.

The date of the observation should always be carefully recorded. For the long-period stars the day is sufficient, but with the short-period and Algol types, it should be set down to the nearest min-

ute. In recording, the time used, whether Standard or local Mean Time, should always be destinctly stated, and whichever is selected at first should always be strictly adherred to, as any departure from it introduces great risk of confusion.

It becomes necessary here to call the observer's attention to the various causes of error that beset observations of this nature, and to point out the precautions necessary to eliminate them, or at least to reduce their effect on the results to a minimum. The observations should be carried on in complete darkness; only as much light should be allowed in the place of observation as is sufficient to read the charts and make notes of the observations, and while observing the eye should be absolutely screened from all extraneous light. No attempt to observe should be made immediately upon coming from a lighted room, and especially if the eyes have been previously engaged in reading or writing by a strong light; in the writer's case, the eye will require at least ten or fifteen minutes to recover its full sensitiveness in these circumstances. The light required for reading circles in setting the telescope, when such are used, is also a disturbing cause. It is strongly recommended that the observer memorize each field, and the comparison-stars used for each variable, so as to avoid as far as possible the consultation of charts, with its necessary disturbance of the eye. It is also greatly to be recommended that he learn to point his telescope upon as many as possible of the telescopic variables without having recourse to the setting circles; this is in many cases quite feasible, as the writer can testify from his own practice, and saves much valuable time.

Care should be taken to avoid and allow for the influence of flying and broken clouds, and to allow for the effect of moonlight and haze; the best way is to avoid observing when these are bad enough to cause serious difficulty; but if it be necessary to do so, these circumstances should be clearly recorded and all doubtful observations marked as such with the usual conventional sign, : for doubtful, and :: for very doubtful, at the time of making the observation. If observations are rejected, this should be done at the time when they are made, not from memory afterward.

There are several causes of subjective error liable to affect observations of this description, the chief of which is "suggestion", or as it is frequently designated, the effect of preconceived ideas or impressions. If the observer has formed an idea in his mind as to what he is likely to see, from previous knowledge or surmise, as from a knowledge of the computed time of a star's phases, he is exceedingly likely to persuade himself that he actually sees

what he has expected to see. Or, fearing this influence, he falls into the sin of over conscientiousness, and errs on the other side. So that in either case the value of his observation is lessened. The more experienced the observer, the more he dreads this source of error, and the more precautions he takes to avoid it. The only safe way is to record exactly what you see, regardless of what you think you ought to see, and leave the star to justify you, rather than the tables.

To avoid this disturbing cause, it is best for the observer to arrange his course of work long in advance, and to note the computed time of phases only so nearly as to allow him to arrange his work for each night. In the case of the ordinary short-period variables, it is best to give one's self no concern as to their dates of maxima and minima, but simply to observe on each good evening. For the Algol-type stars, the writer makes up his list at least a month or two ahead, giving the dates of minima only to the nearest hour, in Greenwich time. The stars of this type, however, are too difficult for the beginner, as a rule, and he will be likely to do little good with them until he has had two or three years' experience.

That this cause of error is a very real influence has been proved by certain physiological experiments, made recently for an entirely different purpose, in the course of which, simply by the indirect suggestion of accompanying circumstances, the subject has been caused to see objects which were actually not present.

Another cause of error is the influence of the position of the group formed by the star and its comparison-stars with relation to the vertical line, which changes with the stars changing hour-angle, so that at different times of the night, or on different nights of the year, the line joining the star and each comparison-star forms widely different angles with the line joining the axes of the eyes in their normal positon. It is the experience of most observers of variable stars, that of any pair of neighboring stars, the one will appear relatively brighter or fainter than the other, according as it is lower or higher than the other. In my own case, this may amount to as much as half a magnitude. This seems to be a purely physiological affair and the explanation of it that suggests itself to me is, that the lower half of the retina, on which the light of the sky falls during the day, becomes blunted in its sensitiveness from that cause, while the upper half, which receives the images of objects below the horizon, which are greatly less luminous, retains its sensitiveness to a greater degree, so that the image of a star falling on the upper part produces

a relatively stronger impression than when it is received by the lower portion.

Some observers are not conscious of this; Mr. Sawyer assures me that he is not; but in my own case it is so strong an influence that I always endeavor to eliminate it by bringing the axis of vision as nearly as possible into coincidence with the line joining the two stars under comparison.

Chandler says; "It is a matter of importance to note carefully in the record of each night's observation, the condition of the atmosphere, the presence of haze, clouds, moonlight, twilight, aurora, etc., as all these circumstances have an influence on the light-estimations. The different illumination of the background of the sky causes decided variations in judging of the comparative brightness of stars of different colors. Red or reddish stars appear brighter by comparison with white ones during twilight or moonlight, than on a dark night. In view of the fact that fully three-quarters of the known variables are of a reddish hue, while their comparison stars are usually nearly colorless, this circumstance requires particular attention in variable star observations. Moreover, it is a peculiarity of red stars that they appear brighter, relatively to white stars, the stronger the optical means employed. It is also the general experience that with all stars of whatever color, the step-intervals are dependent on the size of telescope used. For these reasons it is important that all observations of a series on a given variable be made, as far as possible, with the same optical assistance. In general it will be advisable to observe all variables, whose minima are brighter than the fifth magnitude, with the naked eye; to employ an opera-glass for those whose changes are between the fifth and seventh magnitudes, and a telescope for the fainter ones. A telescope of two, or two and a half inches aperture will suffice to observe the maxima of nearly all" (this was written before the late immense accumulation of very faint photographic variables and the clusters, etc.,) "the telescopic variables, while one of three or four inches aperture will follow many of them through all their phases. In making light comparisons with a telescope, it should be borne in mind that a star near the edge of the field of view appears brighter than in the centre; consequently, if the distance between the variable and a comparison-star is considerable, the step-estimation should be made by bringing each successively into the field, instead of attempting to see both at once; and, even when the distance is moderate, it is best to place them at equal distances from the centre."

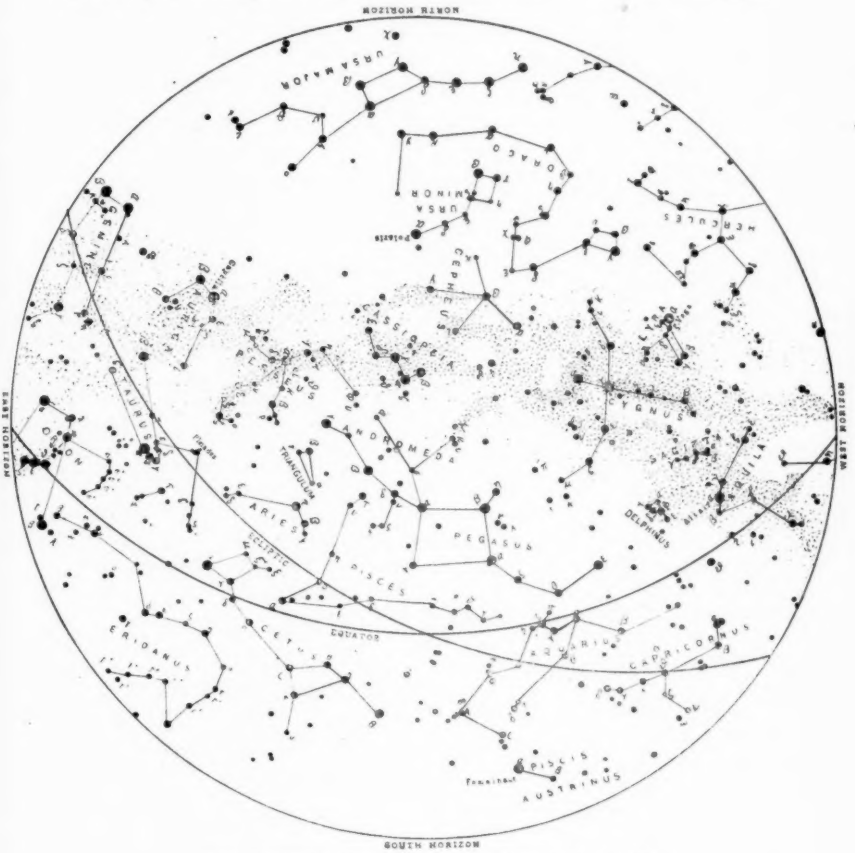
So much for the actual observation; in a future paper, the processes of reduction will be taken up.

Dorchester, Mass., 1905, Sept. 9.

PLANET NOTES FOR NOVEMBER, 1905.

H. C. WILSON.

Mercury will be evening star during this month and will be visible to the naked eye a short time after sunset during the last week of November. The planet will be at geatest elongation, east of the Sun 21° 41′, on Nov. 26. The planet



THE CONSTELLATIONS AT 9 P. M. NOVEMBER 1, 1905.

will be seen toward the southwest at a low altitude and its brightness will not be so great as at the western elongation in September.

Venus is passing around to the farther side of her orbit and therefore waning in brilliancy, but is still conspicuous in the eastern sky in the morning. Her course lies through Virgo and her phase is nearly full.

Mars is passing from Sagittarius into Capricorn and may be seen toward the southwest in the early evening. The conditions for observation are quite unfavorable.

Jupiter is better situated, being at opposition Nov. 23, and having a good high meridian altitude. He is in Taurus between the Pleiades and the Hyades.

Saturn will be at quadrature, 90° east from the Sun, Nov. 18, and may be observed toward the south, in the constellation Aquarius, in the early evening. The planet, being so much brighter than any of the stars in that part of the sky is easily recognized.

Uranus is past the best position for the year but may be found in the early part of the evening in the constellation Sagittarius. It is too faint to be seen without a telescope.

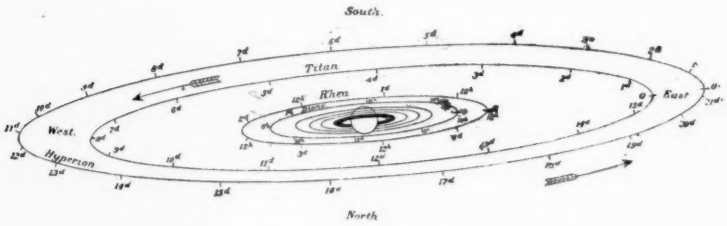
Neptune may be found, with the aid of a telescope in the morning hours, in the constellation Gemini about midway between the stars δ and μ. For its position among the faint stars see chart in February number of Popular Astronomy.

Occultations Visible at Washington.

Date. 1905.	Star's Name.	Magnitude.	IMMERSION. Washington M.T.	IMMERSION. Angle f'm N pt.	EMERSION. Washington M. T.	EMERSION. Angle f'm N pt.	Duration.
			h m	°	h m	°	h m
Oct. 16	48 Tauri	6.3	9 11	101	10 08	223	0 57
16	γ Tauri	3.9	11 43	130	12 24	190	0 41
16	75 Tauri	5.2	17 54	83	19 09	264	1 15
21	54 Cancri	6.3	17 07	179	17 26	205	0 19
30	29 Ophiuchi	6.4	7 12	137	7 53	176	0 41
Nov. 4	42 Capricorni	5.1	4 00	50	5 00	285	1 00
5	τ Aquarii	4.8	3 58	31	4 47	293	0 49
5	58 Aquarii	6.4	4 18	102	5 29	218	1 11
7	4 Ceti	6.3	7 25	347	7 47	318	0 22
9	ν Piscium	4.6	9 05	55	10 34	246	1 29
10	B. A. C. 764	6.3	11 16	22	12 23	286	1 07
17	d^2 Cancri	6.2	11 05	52	11 53	314	0 48
30	ρ Capricorni	5.0	4 08	12	4 46	319	0 38

Satellites of Saturn.

[Central Standard Time; the hours are reckoned from noon. E. = East Elongation; I. = Inferior Conjunction (south of planet); W. = West Elongation; S. = Superior Conjunction (north of planet).]



I. Mimas. Period $0^d\ 22.^h6$.

	h		h		h		h
Oct. 16	9.3 E.	Oct. 25	8.2 W.	Nov. 4	5.7 E.	Nov. 18	9.0 E.
17	8.0 E.	26	6.8 W.	9	10.1 W.	19	7.7 E.
18	6.6 E.	27	5.5 W.	10	8.8 W.	20	6.5 E.
19	5.2 E.	Nov. 1	9.9 E.	11	7.4 W.	21	4.9 E.
23	11.0 W.	2	8.5 E.	12	6.0 W.	27	7.9 W.
24	9.6 W.	3	7.1 E.	13	4.6 W.	28	6.5 W.
						29	5.2 W.

Satellites of Saturn.—Continued.

II. Enceladus. Period $1^d\ 8.^h9$.

		h			h			h			h
Oct.	15	22.3 E.	Oct.	26	21.4 E.	Nov.	6	20.5 E.	Nov.	17	19.6 E.
	17	7.2 E.		28	6.3 E.		8	5.4 E.		19	4.5 E.
	18	16.1 E.		29	15.2 E.		9	14.3 E.		20	13.4 E.
	20	1.0 E.		31	0.1 E.		10	23.2 E.		21	22.3 E.
	21	9.9 E.	Nov.	1	9.0 E.		12	8.1 E.		23	7.4 E.
	22	18.7 E.		2	18.8 E.		13	17.0 E.		24	16.1 E.
	24	3.6 E.		4	2.7 E.		15	1.9 E.		26	1.0 E.
	25	12.5 E.		5	11.6 E.		16	10.7 E.		27	9.9 E.
										28	18.8 E.
										30	3.7 E.

III. Tethys. Period $1^d\ 21.^h3$.

Oct.	17	8.9 E.	Oct.	28	16.8 E.	Nov.	9	0.6 E.	Nov.	20	8.5 E.
	19	6.2 E.		30	14.1 E.		10	21.9 E.		22	5.9 E.
	21	3.5 E.	Nov.	1	11.4 E.		12	19.3 E.		24	3.2 E.
	23	0.8 E.		3	8.7 E.		14	16.6 E.		26	0.5 E.
	24	22.1 E.		5	6.0 E.		16	13.9 E.		27	21.8 E.
	26	19.4 E.		7	3.3 E.		18	11.2 E.		29	19.1 E.

IV. Dione. Period $2^d\ 17.^h7$.

Oct.	18	4.1 E.	Oct.	29	2.8 E.	Nov.	9	1.6 E.	Nov.	20	0.4 E.
	20	21.9 E.		31	20.5 E.		11	19.3 E.		22	18.1 E.
	23	15.4 E.	Nov.	3	14.2 E.		14	13.0 E.		25	11.8 E.
	26	9.1 E.		6	7.9 E.		17	6.7 E.		28	5.5 E.

V. Rhea. Period $4^d\ 12.^h5$.

Oct.	18	23.6 E.	Nov.	1	12.9 E.	Nov.	15	2.2 E.	Nov.	24	3.2 E.
	23	12.0 E.		6	1.3 E.		19	14.7 E.		28	15.7 E.
	28	0.4 E.		10	13.8 E.						

VI. Titan. Period $15^d\ 23.^h3$.

Oct.	16	5.6 I.	Oct.	28	0.8 E.	Nov.	8	22.5 S.	Nov.	21	1.6 W.
	20	3.9 W.	Nov.	1	4.2 I.		12	23.5 E.		24	21.7 S.
	23	23.6 S.		5	2.5 W.		17	3.2 I.		28	22.9 E.

VII. Hyperion. Period $21^d\ 7.^h6$.

Oct.	16.5 S.		Oct.	27.2 I.		Nov.	6.9 S.		Nov.	17.6 I.	
	21.5 E.		Nov.	1.9 W.			11.8 E.			23.3 W.	
										28.3 S.	

VIII. Iapetus. Period $79^d\ 22.^h1$.

Oct.	20.7 S.		Nov.	8.9 E.		Nov.	29.1 I.		Dec.	19.8 W.	

New Asteroids.—The following have been added to the list of new minor planets since our last note:

		Discovered by	at		Local M. T. h	m	R. A. h	m	Decl. °	′	Mag.
1905	QR	Götz	Heidelberg	July 27	13	52.2	20	50.5	+ 4	23	9.5
	QS	Götz	"	26	12	04.0	22	08.6	+16	06	12.3
	QT	Palisa	Vienna	27	13	02.5	23	09.3	— 4	28	13.2
	QU	Palisa	"	30	14	25.9	23	08.8	— 3	43	12.5
	QV	Wolf	Heidelberg	30	13	24.2	22	13.8	— 8	56	12.8
	QX	Wolf	"	30	13	24.2	22	3.9	— 9	18	12.3
	QY	Wolf	"	Aug. 23	11	39.9	22	37.9	— 7	55	11.3

1905 QR turns out to be identical with (216) Cleopatra.
1905 QV is also identical with (263) Dresda.

VARIABLE STARS.

Maxima of Y Lyræ.

		h			h			h			h
Oct.	19-26	3	Nov.	1- 3	4	Nov.	12-18	6	Nov.	27-30	8
	27-31	4		4-11	5		19-26	7			

Approximate Magnitudes of Variable Stars on Sept. 10, 1905.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.
T Androm.	0	17.2	+26	26	10.5 *i*	R Camelop.	14	25.1	+84	17	*f*
T Cassiop.	0	17.8	+55	14	11.5*d*	R Bootis	14	32.8	+27	10	9.5*d*
R Androm.	0	18.8	+38	1	11.5*d*	S Librae	15	15.6	−20	2	11.0*d*
S Ceti	0	19.0	− 9	53	*u*	S Serpentis	15	17.0	+14	40	8.5
S Cassiop.	1	12.3	+72	5	11.3*d*	S Coronae	15	17.3	+31	44	12.0*d*
R Piscium	1	25.5	+ 2	22	*u*	S Urs. Min.	15	33.4	+78	58	8.0 *i*
U Persei	1	52.9	+54	20	9.5*d*	R Coronae	15	44.4	+28	28	6.0 *i*
R Arietis	2	10.4	+24	36	*u*	V "	15	45.9	+39	52	11.5*d*
o Ceti	2	14.3	− 3	26	*u*	R Serpentis	15	46.1	+15	26	9.5*d*
S Persei	2	15.7	+58	8	9.5	R Herculis	16	1.7	+18	38	8.5 *i*
R Ceti	2	20.9	− 0	38	*u*	R Scorpii	16	11.7	−22	42	13.5*f*
U "	2	28.9	−13	35	*u*	S "	16	11.7	−22	39	10.5 *i*
R Trianguli	2	31.0	+33	50	*u*	U Herculis	16	21.4	+19	7	12.2*d*
R Persei	3	23.7	+35	20	*u*	W Herculis	16	31.7	+38	32	8.8*d*
R Tauri	4	22.8	+ 9	56	*u*	R Draconis	16	32.4	+66	58	9.8*d*
S "	4	23.7	+ 9	44	*u*	S Herculis	16	47.4	+15	7	9 0*d*
R Aurigæ	5	9.2	+53	28	11 *d*	R Ophiuchi	17	2.0	−15	58	9.5*d*
U Orionis	5	49.9	+20	10	*u*	T Herculis	18	5.3	+31	0	7.3 *i*
R Lyncis	6	53.0	+55	28	*f*	R Scuti	18	42.2	− 5	49	5.0 *i*
R Gemin.	7	1.3	+22	52	*u*	R Aquilae	19	1.6	+ 8	5	11.5*d*
S Canis Min.	7	27.3	+ 8	32	*s*	R Sagittarii	19	10.8	−19	59	8.5*d*
R Cancri	8	11.0	+12	2	*s*	S "	19	13.6	−19	12	14 *d*
V "	8	16.0	+17	36	*s*	R Cygni	19	14.1	+49	58	14 *f*
S Hydrae	8	48.4	+ 3	27	*s*	RT "	19	40.8	+48	32	10.0
T "	8	50.8	− 8	46	*s*	X "	19	46.7	+32	40	12.3*d*
R Leo. Min.	9	39.6	+34	58	*u*	S "	20	3.4	+57	42	*f*
R Leonis	9	42.2	+11	54	8.5*d*	RS "	20	9.8	+38	28	9.6*d*
R Urs. Maj.	10	37.6	+69	18	12.0*d*	R Delphini	20	10.1	+ 8	47	12.2*d*
R Comae Ber.	11	59.1	+19	20	9.5*d*	U Cygni	20	16.5	+47	35	7.0 *i*
T Virginis	12	9.5	− 5	29	*s*	V "	20	38.1	+47	47	10 *i*
R Corvi	12	14.4	−18	42	*s*	T Aquarii	20	44.7	− 5	31	8.0 *i*
Y Virginis	12	28.7	− 3	52	*s*	R Vulpec.	20	59.9	+23	26	12.0*d*
T Urs. Maj.	12	31.8	+60	2	*f*	T Cephei	21	8.2	+68	5	8.8*d*
R Virginis	12	33.4	+ 7	32	*s*	S "	21	36.5	+78	10	*u*
S Urs. Maj.	12	39.6	+61	38	7.5 *i*	S Lacertae	22	24.6	+39	48	9.0 *i*
U Virginis	12	46.0	+ 6	6	*s*	R "	22	38.8	+41	51	14.2*d*
V "	13	22.6	− 2	39	*s*	S Aquarii	22	51.8	−20	53	14 *f*
R Hydrae	13	24.2	−22	46	*s*	R Pegasi	23	1.6	+10	0	9.3*d*
S Virginis	13	27.8	− 6	41	*s*	S "	23	15.5	+ 8	22	9.5
R Can. Ven.	13	44.6	+40	2	11.5*d*	R Aquarii	23	38.6	+15	50	*u*
S Bootis	14	19.5	+54	16	12.5*d*	R Cassiop.	23	53.3	+50	50	10.3*d*

NOTE:—*f* denotes that the variable is probably fainter than the magnitude 13; *i*, that the light is increasing; *d*, that the light is decreasing; *s*, that it is near the Sun; and *u*, that its magnitude is unknown.

From observations made at the Leander McCormick, Vassar College, Whiteside and Harvard Observatories.

Maxima of U Y Cygni.

	h		h		h		h
Oct. 16	3	Oct. 27	8	Nov. 7	13	Nov. 18	18
17	6	28	11	8	16	19	21
18	9	29	14	9	19	21	0
19	11	30	17	10	22	22	3
20	14	31	20	12	1	23	6
21	17	Nov. 1	22	13	4	24	9
22	20	3	1	14	7	25	12
23	23	4	4	15	10	26	15
25	2	5	7	16	13	27	17
26	5	6	10	17	15	29	20
						29	23

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time. To reduce to Central Standard time subtract 6 hours, or for Eastern time subtract 5 hours.]

U Cephei.

	d	h
Oct.	17	10
	19	22
	22	9
	24	21
	27	9
	29	21
Nov.	1	9
	3	20
	6	8
	8	20
	11	8
	13	20
	16	8
	18	19
	21	7
	23	19
	26	7
	28	19

Z Persei.

	d	h
Oct.	18	14
	21	15
	24	17
	27	18
	30	20
Nov.	2	21
	5	22
	9	0
	12	1
	15	2
	18	4
	21	5
	24	6
	27	8
	30	9

Algol.

	d	h
Oct.	18	14
	21	10
	24	7
	27	4
	30	1
Nov.	1	22
	4	19
	7	15
	10	12
	13	9
	16	6
	19	3
	21	23
	24	20
	27	17
	30	14

RT Persei.

	d	h
Oct.	16	9
	17	5
	18	2
	18	22
	19	19
	20	15
Oct.	21	11
	22	8
	23	4
	24	1
	24	21
	25	17
	26	14
	27	10
	28	6
	29	3
	29	23
	30	20
	31	16
Nov.	1	12
	2	9
	3	5
	4	2
	4	22
	5	18
	6	15
	7	11
	8	7
	9	4
	10	0
	10	21
	11	17
	12	13
	13	10
	14	6
	15	3
	15	23
	16	19
	17	16
	18	12
	19	8
	20	5
	21	1
	21	22
	22	18
	23	14
	24	11
	25	7
	26	4
	27	0
	27	20
	28	17
	29	13
	30	10

λ Tauri.

	d	h
Oct.	19	18
	23	17
	27	16
	31	15
Nov.	4	14
	8	13
	12	12
	16	10
	20	9
	24	8

λ Tauri.

	d	h
Nov.	28	7

R Canis Maj.

	d	h
Oct.	16	20
	17	23
	19	3
	20	6
	21	9
	22	12
	23	16
	24	19
	25	22
	27	2
	28	5
	29	8
	30	11
	31	15
Nov.	1	18
	2	21
	4	0
	5	4
	6	7
	7	10
	8	13
	9	17
	10	20
	11	23
	13	2
	14	6
	15	9
	16	12
	17	16
	18	19
	19	22
	21	1
	22	5
	23	8
	24	11
	25	14
	26	18
	27	21
	29	0
	30	3

Y Camelopard.

	d	h
Oct.	17	3
	20	10
	23	17
	27	1
	30	8
Nov.	2	15
	5	22
	9	6
	12	13
	15	21
	19	4
	22	11
	25	18
	29	2

RR Puppis

	d	h
Oct.	18	8
	24	18
	31	5
Nov.	6	15
	13	1
	19	11
	26	22

V Puppis.

	d	h
Oct.	17	0
	18	11
	19	22
	21	9
	22	20
	24	7
	25	18
	27	5
	28	16
	30	3
	31	14
Nov.	2	0
	3	11
	4	22
	6	9
	7	20
	9	7
	10	18
	12	5
	13	16
	15	3
	16	14
	18	0
	19	11
	20	22
	22	9
	23	20
	25	7
	26	18
	28	5
	29	16

S Cancri.

	d	h
Oct.	24	9
Nov.	2	21
	12	9
	21	20

S Antliæ.

Period $7^h\ 46^m.8$

	d	h
Oct.	17	2
	18	1
	19	0
	20	0
	20	23
	21	22
	22	22
	23	21
	24	20
	25	20
	26	19
	27	18

S Antliæ.

	d	h
Oct.	28	18
	29	17
	30	17
	31	16
Nov.	1	15
	2	15
	3	14
	4	13
	5	13
	6	12
	7	11
	8	11
	9	10
	10	9
	11	9
	12	8
	13	7
	14	7
	15	6
	16	5
	17	5
	18	4
	19	3
	20	3
	21	2
	22	1
	23	1
	24	0
	24	23
	25	23
	26	22
	27	21
	28	21
	29	20
	30	19

S Velorum.

	d	h
Oct.	20	11
	26	9
Nov.	1	7
	7	6
	13	4
	19	3
	25	1
	30	23

W Urs. Maj.

Oct. 15-31 19
Nov. 1-15 19
16-30 20

U Ophiuchi.

	d	h
Oct.	16	5
	17	1
	17	21
	18	17
	19	13
	20	10
	21	6
	22	2
	22	22

Minima of Variable Stars of the Algol Type.—Continued.

U Ophiuchi.

	d	h
Oct.	23	18
	24	14
	25	10
	26	6
	27	3
	27	23
	28	19
	29	15
	30	11
	31	7
Nov.	1	3
	1	23
	2	20
	3	16
	4	12
	5	8
	6	4
	7	0
	7	20
	8	16
	9	13
	10	9
	11	5
	12	1
	12	21
	13	17
	14	13
	15	9
	16	6
	17	2
	17	22
	18	18
	19	14
	20	10
	21	6
	22	2
	22	23
	23	19
	24	15
	25	11
	26	7
	27	3
	27	23
	28	20
	29	16
	30	12

Z Herculis.

	d	h
Oct.	16	0
	17	21
	20	0
	21	21
	24	0
	25	21
	28	0
	29	21
Nov.	1	0
	2	21
	4	23
	6	20
	8	23

Z Herculis.

	d	h
Nov.	10	20
	12	23
	14	20
	16	23
	18	20
	20	23
	22	20
	24	23
	26	20
	28	22
	30	19

RS Sagittarii.

	d	h
Oct.	17	20
	20	6
	22	16
	25	2
	27	12
	29	22
Nov.	1	7
	3	17
	6	3
	8	13
	10	23
	13	9
	15	19
	18	5
	20	15
	23	1
	25	11
	27	21
	30	7

V Serpentis.

	d	h
Oct.	18	13
	22	0
	25	11
	28	22
Nov.	1	9
	4	20
	8	7
	11	18
	15	5
	18	16
	22	2
	25	13
	29	0

RX Herculis.

	d	h
Oct.	16	16
	17	14
	18	11
	19	8
	20	6
	21	3
	22	1
	22	22
	23	19
	24	17
	25	14
	26	11
	27	8

RX Herculis.

	d	h
Oct.	28	6
	29	3
	30	1
	30	22
	31	19
Nov.	1	17
	2	14
	3	11
	4	9
	5	6
	6	3
	7	1
	7	22
	8	19
	9	17
	10	14
	11	11
	12	9
	13	6
	14	4
	15	1
	15	22
	16	20
	17	17
	18	14
	19	12
	20	09
	21	6
	22	4
	23	1
	23	22
	24	20
	25	17
	26	14
	27	12
	28	9
	29	6
	30	4

RV Lyræ.

	d	h
Oct.	18	8
	21	22
	25	13
	29	3
Nov.	1	17
	5	8
	8	22
	12	13
	16	3
	19	17
	23	8
	26	22
	30	12

U Sagittæ.

	d	h
Oct.	18	5
	21	14
	24	23
	28	8
	31	17
Nov.	4	3

U Sagittæ.

	d	h
Nov.	7	12
	10	21
	14	6
	17	15
	21	10
	24	9
	27	18

SY Cygni.

	d	h
Oct.	18	7
	24	7
	30	7
Nov.	5	7
	11	7
	17	8
	23	8
	29	8

WW Cygni.

	d	h
Oct.	18	7
	21	14
	24	22
	28	6
	31	13
Nov.	3	21
	7	4
	10	12
	13	19
	17	3
	20	11
	23	18
	27	2
	30	10

SW Cygni.

	d	h
Oct.	18	12
	23	2
	27	16
Nov.	1	6
	5	20
	10	9
	14	23
	19	13
	24	2
	28	16

VW Cygni.

	d	h
Oct.	22	6
	30	17
Nov.	8	3
	16	14
	25	0

UW Cygni.

	d	h
Oct.	17	12
	20	23
	24	10
	27	21
	31	8
Nov.	3	18
	7	5
	10	16
	14	3

UW Cygni.

	d	h
Nov.	17	14
	21	1
	24	11
	27	22

W Delphini.

	d	h
Oct.	16	12
	21	8
	26	3
	30	22
Nov.	4	18
	9	13
	14	8
	19	4
	23	23
	28	18

Y Cygni.

	d	h
Oct.	17	2
	18	11
	20	2
	21	21
	23	1
	24	11
	26	2
	27	11
	29	2
	30	11
Nov.	1	1
	2	11
	4	1
	5	11
	7	1
	8	11
	10	1
	11	10
	13	1
	14	10
	16	1
	17	10
	19	1
	20	10
	22	1
	23	10
	25	1
	26	10
	29	10

VV Cygni.

	d	h
Oct.	17	4
	18	15
	20	3
	21	14
	23	2
	24	13
	26	1
	27	12
	29	0
	30	11
	31	23
Nov.	2	10
	3	21

Minima of Variable Stars of the Algol Type.—Continued.

VV Cygni.		VV Cygni.		VV Cygni.		VV Cygni.		UZ Cygni.	
d	h	d	h	d	h	d	h	d	h
Nov. 5	9	Nov. 12	18	Nov. 20	3	27	12	Oct. 2	1
6	20	14	5	21	15	29	0	Nov. 2	9
8	8	15	17	23	2	30	11	Dec. 3	16
9	19	17	4	24	14				
11	7	18	16	26	1				

Variable Stars of Short Period not of the Algol Type.

Star's Name	Minimum.		Maximum.			Minimum.		Maximum.	
	d	h	d	h		d	h	d	h
T Monocerotis	Oct. 16	2	Oct. 24	1	RV Scorpii	Oct. 27	9	Oct. 28	18
T Vulpeculæ	16	14	17	23	VY Cygni	27	15	29	17
R Triang. Austr.	16	17	17	17	δ Cephei	27	19	29	4
U Aquilae	16	19	18	23	T Crucis	27	22	29	23
η Aquilae	16	21	19	6	V Carinae	27	23	30	3
S Crucis	16	22	18	10	W Sagittarii	28	2	31	2
δ Cephei	17	2	18	11	Y Sagittarii	28	6	30	8
V Velorum	17	5	18	4	β Lyræ	28	6	31	8
T Velorum	17	21	19	6	X Cygni	29	4	Nov. 3	7
S Sagittae	17	21	21	7	X Sagittarii	29	15	1	12
U Sagittarii	18	17	21	16	T Vulpeculae	29	22	Oct. 31	7
VY Cygni	19	18	21	20	R Triang.Austr.	30	6	31	6
R Triang. Austr.	20	2	21	2	V Velorum	30	7	31	6
V Centauri	20	6	21	17	U Aquilæ	30	20	Nov. 2	0
W Sagittarii	20	12	23	12	S Crucis	30	23	1	11
S Triang. Austr.	20	13	22	15	V Centauri	31	5	1	16
T Vulpeculae	21	1	22	10	S Muscae	31	6	3	17
T Crucis	21	3	23	4	η Aquilae	31	6	2	15
V Carinae	21	6	23	10	W Geminorum	31	12	3	3
RV Scorpii	21	8	22	17	T Velorum	31	18	2	3
R Crucis	21	10	22	19	U Vulpeculae	31	19	2	22
S Crucis	21	14	23	2	S Normae	Nov. 1	2	5	11
V Velorum	21	14	22	13	U Sagittarii	1	5	4	4
S Muscae	21	15	25	1	R Crucis	2	2	3	11
β Lyrae	21	18	25	1	δ Cephei	2	4	3	13
S Normae	22	8	26	17	S Triang. Austr.	2	5	4	7
δ Cygni	22	10	23	19	κ Pavonis	2	5	6	14
T Velorum	22	12	23	21	RV Scorpii	2	11	3	20
Y Sagittarii	22	12	24	14	R Triang. Austr.	2	16	3	16
X Sagittarii	22	15	25	12	T Vulpeculae	3	8	4	17
TX Cygni	22	15	27	18	T Crucis	3	15	5	16
R Triang. Austr.	23	11	24	11	V Carinæ	3	15	5	19
W Geminorum	23	12	26	3	S Sagittae	3	16	7	2
U Aquilae	23	19	26	0	V Velorum	3	16	4	15
U Vulpeculae	23	20	25	23	β Lyrae	3	17	7	0
η Aquilae	24	1	26	10	ζ Geminorum	4	8	9	8
κ Pavonis	24	3	28	12	VY Cygni	4	11	6	13
ζ Geminorum	25	5	30	5	W Sagittarii	4	16	7	16
T Vulpeculae	25	11	26	20	S Crucis	4	16	6	4
U Sagittarii	25	11	28	10	T Velorum	5	10	6	19
V Centauri	25	17	27	4	X Sagittarii	5	15	8	12
V Velorum	25	22	27	21	V Centauri	5	17	7	4
S Sagittae	26	6	29	16	R Triang. Austr.	6	1	7	1
S Crucis	26	7	27	19	TX Cygni	6	9	11	12
Y Ophiuchi	26	16	32	21	δ Cephei	7	13	8	22
S Triang. Austr.	26	20	28	22	T Vulpeculæ	7	19	9	4
R Triang. Austr.	26	21	27	21	U Aquilae	7	20	10	0
T Velorum	27	3	28	12	R Crucis	7	22	9	7
R Crucis	27	6	28	15	η Aquilae	7	22	10	7

Variable Stars of Short Period not of the Algol Type.—(Continued.)

	Minimum.		Maximum.	
	d	h	d	h
U Sagittarii	Nov. 7	23	Nov. 10	22
W Geminorum	8	0	10	15
V Velorum	8	1	9	0
RV Scorpii	8	12	9	21
S Triang. Austr.	8	13	10	15
U Vulpeculae	8	19	10	23
Y Sagittarii	8	20	10	22
S Crucis	9	8	10	20
R Triang. Austr.	9	10	10	10
S Muscae	9	22	13	9
T Velorum	10	3	11	12
β Lyrae	10	4	13	6
T Crucis	10	9	12	10
V Carinae	10	9	12	13
δ Normae	10	20	15	5
V Centauri	11	5	12	17
κ Pavonis	11	7	15	16
S Sagittae	12	1	15	11
T Minocerotis	12	3	20	1
T Vulpeculae	12	5	13	14
W Sagittarii	12	7	15	7
VY Cygni	12	8	14	10
V Velorum	12	10	13	9
X Sagittarii	12	16	15	13
R Triang. Austr.	12	19	13	19
Y Ophiuchi	12	19	19	0
δ Cephei	12	21	14	6
W Sagittarii	12	22	15	22
R Crucis	13	17	15	2
U Aquilae	13	21	16	1
S Crucis	14	1	15	13
ζ Geminorum	14	12	19	12
X Cygni	14	13	19	16
RV Scorpii	14	14	15	23
η Aquilae	14	14	17	23
T Velorum	14	17	16	2
U Sagittarii	14	17	17	16
S Triang. Austr.	14	20	16	22
W Geminorum	15	18	18	9
R Triang Austr.	16	5	17	5
β Lyræ	16	15	19	22
T Vulpeculae	16	16	18	1
V Centauri	16	17	18	4
U Vulpeculae	16	18	18	21
V Carinae	17	1	19	5
T Crucis	17	2	19	3
V Velorum	17	7	18	6
δ Cephei	18	6	19	15
S Crucis	18	17	20	5
T Velorum	19	8	20	17
R Crucis	19	13	20	22
S Muscae	19	13	23	0
R Triang. Austr.	19	14	20	14
X Sagittarii	Nov. 19	16	Nov. 22	13
W Sagittarii	19	21	22	21
VY Cygni	20	4	22	6
κ Pavonis	20	9	24	18
S Sagittae	20	10	23	20
S Normae	20	14	24	23
RV Scorpii	20	15	22	0
U Aquilae	20	21	23	1
T Vulpeculæ	21	2	22	12
TX Cygni	21	2	26	5
V Velorum	21	4	22	3
S Triang. Austr.	21	4	23	6
U Sagittarii	21	10	24	9
η Aquilae	21	18	24	3
V Centauri	22	5	23	16
R Triang. Austr.	23	0	24	0
W Geminorum	23	11	26	2
β Lyræ	23	12	26	14
δ Cephei	23	15	25	0
V Carinae	23	18	25	22
T Crucis	23	20	25	21
T Velorum	23	23	25	8
S Crucis	24	10	25	22
ζ Geminorum	24	16	29	16
U Vulpeculae	24	17	26	20
R Crucis	25	9	26	18
T Vulpeculae	25	12	26	21
V Velorum	25	13	26	12
R Triang. Austr.	26	9	27	9
RV Scorpii	26	17	28	2
X Sagittarii	26	17	29	14
W Sagittarii	27	11	30	11
S Triang. Austr.	27	12	29	14
V Centauri	27	16	29	3
U Aquilae	27	22	30	2
VY Cygni	28	1	30	3
S Crucis	28	2	29	14
U Sagittarii	28	4	31	3
T Velorum	28	14	29	23
η Aquilae	28	23	31	8
δ Cephei	29	0	30	9
S Muscae	29	6	32	17
S Sagittae	29	7	32	17
κ Pavonis	29	12	33	21
β Lyræ	29	13	32	20
R Triang. Austr.	29	18	30	18
V Velorum	29	22	30	21
T Vulpeculae	29	22	31	8
Y Ophiuchi	29	22	36	3
S Normae	30	9	34	18
V Carinæ	30	10	32	14
T Crucis	30	13	32	14

Maxima of RZ Lyræ.

	h		h		h		h
Oct. 16	18	Oct. 21	21	Oct. 25	23	Oct. 30	1
17	19	22	21	27	0	31	2
18	19	23	22	28	0	Nov. 1	2
20	20	24	23	29	1	3	3

Maxima of RZ Lyræ.

		h			h			h			h
Nov.	4	3	Nov.	11	7	Nov.	18	11	Nov.	25	15
	5	4		12	7		18	11		26	16
	6	4		13	8		20	12		27	16
	7	5		14	8		21	13		28	17
	8	5		15	9		22	13		29	17
	9	6		16	9		23	14		30	18
	10	6		17	10		24	15			

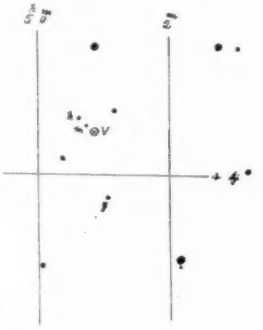
Variable Star Notes.

V ORIONIS

A maximum of V Orionis, which occurred between December the 25th 1904 and January 11th 1905 was observed as follows:

1904, November 8. Equal to n.
November 30. The same.
December 2, 4, 6, 13. The same.
December 16. Brighter than n, not equal to f.
December 25. Nearly equal to f.
December 31. Equal to f. Brighter than n.
1905, January 2, and 9. The same.
January 11. Less than f, equal to n.
January 24, 28. Slightly less than n.
February 7, 9. Slightly less than n.
February 21. Between n and m.
March 5. Invisible.

The comparison stars are between 8 and 12 magnitude and in the field of view with the variable as shown on the accompanying map.

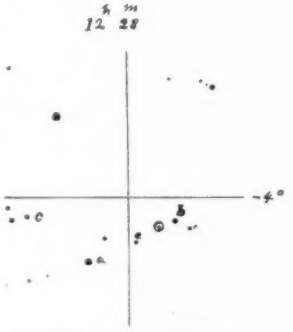


VICINITY OF V ORIONIS.

Y VIRGINIS

The accompanying map may aid in finding this variable which is about three degrees southwest of Gamma Virginis. The stars represented are chieflythose conspicuous in a four inch lens. A maximum predicted for May 10th was observed as follows:

1905, April 2 Equals e. Less than d Brighter that f.
April 25 Equals e. Less than a Brighter than d.
May 4 The same.
May 9 Not fully equal to e.
May 16 and 21. Equaltoe. Brighter than f.



VICINITY OF Y VIRGINIS.

July 2 Equal to e. Though it attained only 9 magnitude at maximum the slow decline to minimum cannot be well observed on account of low altitude.

R HYDRÆ.

The comparison stars used for the recent maximum of R Hydræ were Gamma of 3.4 magnitude and Psi of 5.4, both conveniently near in the same constellation; and also Alpha Corvi 4.3, 69 Virginis, 5.0 and 2 Centaurus 4.6.

1905, April 27, May 1, 4, 8, 21, Nearer to the lustre of Gamma than to that of Psi with the naked eye and opera glass, and brighter than Alpha Corvi in opera glass but only equal to it with the naked eye.
May 29 Brighter than 69 Virginis and equal to 2 in the head of the Centaur.
June 5 Dimmer than 69 Virginis and about two tenths brighter than Psi Hydræ.
12 Very slightly dimmer than Psi.
18 Distinctly less than Psi.
July 1 About half a magnitude less than Psi. Having the long period of 425 days, a minimum is not expected until the beginning of December next.

W LYR.Æ.

1904 December 18 Not more than 11.5 magnitude.
31 Barely discernible. Probably less than 12 magnitude.
1905 January 10 Not discernible though stars of about 12 magnitude were seen in clear areas between clouds.
27 Not visible. Morning clear.
February 6 Not visible. Morning clear.
March 27 Near midnight. Altitude 22°. Of 8.8 magnitude.
April 4, 11:40 Of 9 magnitude according to the adjacent comparison stars a slight fluctuation occurred not due to moonlight effects.
26 Of 8.7 magnitnde.
May 5 About two tenths brighter than adjacent star classed 8.1 magnitude.
9 The same.
19 Equals 8.1 magnitude.
21 Of 8.4 magnitude.
29 Of 8.7 magnitude.
31 The same.
June 5 Of 8.8.
10 The same.
18 About 9.6 magnitude.
22 Of 10 magnitude.
26 Of 10.3 magnitude.
30 Of 10.8 magnitude.

V HYDR.Æ.

Being familiar with the neighborhood of this variable, I observed it on eight evenings during March and April of the present year, when to a passing glance, it seemed like an ordinary yellow star of less than ninth magnitude. Attentive observation was needed to discern its crimson hue in a four inch telescope. Its period being long and irregular, this minimum was not anticipated

ROSE O'HALLORAN.

San Francisco, July 3, 1905.

New Variable 78.1905 Virginis.—In *A. N.* 4039 Messrs M. and G Wolf announce this new variable as discovered on the photographs taken at Heidelberg. Photographs for its study are available extending from March 1892 to March 1905. These show a variation of at least four magnitudes, between 12.5 and 8.3. The period is uncertain. The position for 1900.0 is

R. A. $12^h\ 20^m\ 07^s$ Decl. $+ 1°\ 19'\ 25''$

New Variable of the Algol Type 79.1905 Cephei.—In *A. N.* 439 Professor W. Ceraski calls attention to a new Algol-type variable in the constellation Cepheus, which was discovered by Mme. L. Ceraski on the Moscow photographs. Its position is

1855	R. A. $4^h\ 40^m\ 51^s$	Decl.	$+80°\ 01'.0$
1900	$4\ 48\ 34$		$+80\ \ 05\ .8$

Its magnitude is generally about 9.5, but on Oct. 1, 1904 and July 14, 1905 it was as faint as the twelfth magnitude. The period is undetermined.

GENERAL NOTES.

Attention is called especially to the change in subscription price, and other changes in the publication that will be made at the beginning of the year 1906.

Nova Aquilae No. 2. A new star in the constellation Aquila was discovered this morning by Mrs. Fleming from an examination of the Draper Memorial photographs. Its approximate position for 1900 is in R. A. $= 18^h\ 56.9^m$, Dec. $= -4°\ 34'$, so that it precedes the bright star λ Aquila., 4.0^m, north $28'$. A photograph of its spectrum on August 18, 1905 shows the hydrogen lines Hδ, Hγ, and Hβ, bright and broad, also faint traces of the bright bands 4472 and 4646. Its magnitude was then about 6.5. On August 21, its magnitude was 7.5 and on August 26, 10.0. A plate taken on August 10, 1905, shows stars of the magnitude 9.5 but does not show the Nova. A plate taken with the Bruce Telescope at Arequipa, on August 15, 1903, and having an exposure of four hours, shows stars of the sixteenth magnitude but no object that can with certainty be identified as the Nova.

Astronomical Bulletin, No. 197. EDWARD C. PICKERING.
Harvard College Observatory,
Cambridge, Mass., Aug. 31, 1905.

Minor Planet Urda.—A telegram has been received at Harvard College Observatory from Professor Kreutz at Kiel stating that the minor planet Urda was observed by Palisa September 4. 416 G. M. T. in R. A. $22^h\ 27^m\ 47.^s5$ and Decl. $-9°\ 04'\ 45''$.

Its magnitude on Aug. 31, was 11.0 and on Sept. 5, 12.0.

Astronomical Bulletin, 198,
Harvard College Observatory,
Cambridge, Mass., Sept. 6, 1905.

Halley's Comet.—The notices below are submitted as addenda to my short bibliography of this comet, published in *Smithsonian Miscellaneous Collections* (*quarterly issue*), vol. 3, pt. 1, (no. 1580, June 10, 1905): pp. 69—74. [Noticed in the *Library Journal*, 30:439.]

MCPIKE, EUGENE FAIRFIELD. Halley's Comet and its discoverer. (*The Observatory*, 28, no. 358 (June, 1905): 256—257.)

PICKERING, WILLIAM H. [Halley's Comet.] (In the Encyclopedia Americana, vol. 4, New York and Chicago: The Americana Co., 1904, *See article* Comet.) Expresses opinion that "very likely the chief reason for the comet's relative faintness in 1835 is that the material which formed the tail has been largely used up by its frequent visits to the Sun, and that it will thus never again present the brilliancy of its past appearances." See, also, similar intimation by Alex von Humboldt, in his Cosmos.

[RIGAUD, STEPHEN PETER.] 1774—1839. Some account | of | Halley's | Astronomiæ Cometicæ | Synopsis, | which contains his investigation | of the orbits of comets. | Jam patet horrificis quæ sit via flexa cometis. | Oxford, | Printed by S. Collingwood, printer to the University, | for J. H. Parker; | and Whittaker and Co., London. | MDCCCXXXV. | *Pamphlet signed at end*: "S. P. Rigaud." p. 24. The foregoing notice was kindly supplied the writer by the Librarian of the Bodleian Library, Oxford, with full collation here omitted.

EUGENE FAIRFIELD MCPIKE.

Chicago, 10 Aug, 1905.

Mr. Buchanan and the Doctrine of Limits. It appears to me that my friend Mr. Buchanan has not a very firm grip on the Differential Calculus as developed by the method of limits. In page 319 Art. 24 of the June and July number he comments on an example given in Haddon's Differential Calculus and shows pretty clearly that he fails to grasp fully the significance of the operation of differentiation.

With Haddon, he assumes the equation

$$u = x^3 \tag{1}$$

and giving x the increment h we have

$$u_1 = (x + h)^3$$
$$= x^3 + 3x^2h + 3x\,h^2 + h^3 \tag{2}$$

hence
$$u_1 - u = 3x^2h + 3x\,h^2 + h^3 \tag{3}$$

and
$$\frac{u_1 - u}{h} = 3x^2 + 3x\,h + h_2 \tag{4}$$

Then Mr. Buchanan says "Now the first term of this expression for the ration $\frac{(u_1 - u)}{h}$ being $3x^2$, it is obvious that h may undergo any change of value whatever without affecting the first term" all of which is true; then he goes on to say, "Let h continually decrease in value until it is $= 0$. May it? Most assuredly it may; but this sophistry keeps out of sight that the first member becomes infinite from which nothing can then be proved;" Not so. There is no sophistry is assuming that h "continually decreases in value" nor does the first member become infinite. When h becomes absolutely zero, then the first member of (4) takes the form $\frac{0}{0}$ which may represent any quantity whatever and in this particular example it represents $3x^2$, the differential coefficient.

There is no inconsistency whatever in this process of differentiation, which is what Mr. Buchanan is vainly trying to show.

In actual practice I think teachers of the Calculus do not regard h as absolutely zero but an infinitesimally small quantity represented by dx, and the first member of (3) by du; hence (3) may be written thus

$$du = 3x^2\,dx + 3x\,dx^2 + dx^3$$

but dx^2 and dx^3 being infinitesimals of the second and third order respectively, are infinitely small compared with dx and therefore may be omitted; then we have

$$\frac{du}{dx} = 3x^2$$

in which du and dx are not absolute zeros but infinitesimally small quantities, du however being $3x^2$ times greater than dx. In this view of the subject an infinitesimal quantity is *not* one which is so small that there can be no smaller, for if that were the case there could be no comparison of du and dx.

Mr. Buchanan however would have us believe, that the first member of (4) is infinite while the second member is finite or in other words

$$\text{infinity} = \text{a finite quantity}$$

which is absurd.

Mr. Buchanan's concluding remarks are certainly unique. He asks "Can the method of limits show the second differential coefficient"? Certainly it can. Again he asks, "can it be derived by another infinitely small quantity k?" Most certainly it can, for we may put $v = 3x^2$ (using v for $\frac{du}{dx}$) and proceed as before and arrive at $\frac{dv}{dx} = 6x$, or in the established notation, $\frac{d^2u}{dx^2} = 6x$, and its derivation follows precisely the same law which he says is "the very point he wishes to know."

J. Morrison.

Washington, D. C.
June 20, 1905.

Recent Lick Observatory Work.—In Lick Observatory Bulletin No. 80, Professor Aitken has given the results of his recent investigation of the orbit

of the binary system, ξ Scorpii (Σ 1998). He finds from an examination of all the observations to 1905 a period of 44.5 years. This system has been the subject of computation by six eminent astronomers in the last fifty years, commencing with Madler in 1846, and followed by Thiele, Flammarion, Doberck, Schorr and See, but with a single exception, all the measures subsequent to about 1858 were discussed with an error of 180° in the several position angles, the resulting periods being about double the true value. Thiele in 1856 made a proper distribution of the observed positions, and deduced a period of 49 years, which was as near the true value as could be expected from the available material at that time. A complete revolution has been made since, and it is not likely that any very material changes will be found in the elements as given by Professor Aitken. His measures give the position of the companion in two quadrants where it had never previously been seen, and so the form of the apparent ellipse is definitely fixed by good measures for the entire revolution.

Lick Observatory Bulletin No. 77 contains Professor Hussey's Tenth Catalogue of 100 new double stars, discovered with the 12-and 36-inch refractors of the Lick Observatory. Most of the measures were made with the latter instrument. They are nearly all small telescopic stars, many of them near the DM limit, but for the most part very close and difficult objects, and much too difficult for most telescopes and localities. Three stars in this list should have been omitted as not being new. This catalogue makes the total number of Professor Hussey's discoveries eleven hundred, a remarkable piece of work, considering the time employed, even for as favorable a place as Mt. Hamilton. This is probably the conclusion of his work at that place in this department, as he has severed his connection with the Lick Observatory to take a position in the University of Michigan. As the astronomical outfit at Ann Arbor is of the most antiquated description and out of date ages ago, it is not likely that he will be able to continue at that place any of his micrometrical work carried on so successfully at Mt. Hamilton.

S. W. Burnham.

Total Solar Eclipse Aug. 30-31, 1905.—At this writing Sept. 12, only a general idea of the results obtained by the various expeditions that observed the total eclipse of the Sun on Aug. 30-31, of this year, can now be given. More definite information will reach us for a subsequent number. We append the following from the September, 1905, *Observatory*.

The state of tension amongst the various eclipse parties, and indeed amongst the public generally, is now over. At this early stage we can do no more than give a general idea of the success attending the expeditions so far as weather is concerned. Definite results will come after the development and discussion of the various photographs. It may be well to recall a few of the principal features. The central line of the eclipse ran through Arabia, across the Red Sea and along the northern part of Africa, across the Mediterranean and northern Spain. After crossing the Atlantic it crossed Labrador.

Prof. Turner and Mr. Bellamy, at Assouan, in Egypt, had a cloudless sky, somewhat hazy. The corona had prominent streamers in the sun-spot zones, those on the eastern side being the longer and less divergent, the longest, opposite the large sun-spot, being about two million miles. The hooked rays peculiar to the 1870 eclipse were visible at the northern pole, and many large prominences were seen.

Passing to Sfax, where the Astronomer Royal and Mr. Dyson are located, we find that close up to the eclipse the Sun was obscured by clouds, which fortunately cleared sufficiently to permit of successful observations. The appearance of the corona was that of pink flames tinged with magenta, and in the northeast and southwest direction extended to two solar diameters. Totality lasted 3 minutes and 25 seconds, the temperature dropped 10 degrees, and many stars were seen. Sir William Christie anticipates good results from the photographs, which are on a four-inch scale.

We are extremely glad to record success at the next post. Prof. Todd, at Tripoli, had excellent weather, and managed with his automatic telescopic camera to obtain no less than 250 photographs. At Guelma, in Algeria, where M. Trépied, of the Observatory at Algiers, and MM. Stephan and Borelly, of Marseilles, are stationed, splendid weather was experienced, Mercury, Regulus and Venus being seen as soon as the light began to fail. The solar corona was brilliant, not extensive, and fairly evenly distributed around the Sun's limb. Some

fine prominences were seen, and the phenomenon of Baily's beads is especially mentioned. The eclipse wind rose at the beginning of totality, and moving shadow-stripes were seen along the ground. At Malta the weather was favorable. At Palma (Majorica) is a large concourse of astronomers, including Sir Norman Lockyer, Dr. Lockyer, Professor Leahy of Sheffield, M. Gautier of Geneva, Drs. Black and Hunter of Edinburgh, Mr. and Mrs. Crommelin, Miss Everett, and Mr. and Mrs. Hollis as representing the *Observatory*. Mr. Hollis telegraphs that the corona was of the type observed by Brothers in 1870, with a fairly distributed corona, and hooked streamers at the poles. Clouds prevented perfectly satisfactory observations of the extent of the streamers, which probably stretched to two solar diameters. Prominences were seen on the north-east and south-west limbs. Mercury, Venus, and the more prominent stars of Leonis were seen.

Many other reports are to come in, but the above are ample to show that the 1905 eclipse has been a most successful one from an observational point of view and the various expeditions are to be congratulated.

The stay-at-homes have not been so fortunate. Elaborate preparations were made at Greenwich, not only to take photographs, but to obtain observations for fixing the place of the Moon. The sky was overcast, and observations were quite hopeless. An energetic observer who ascended to the Golden Gallery of St. Paul's Cathedral just glimpsed the Sun; at the Marble Arch it was seen several seconds at a time. In the country the weather was more favorable.

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